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# DYNAMIC FLIR TARGET ACQUISITION PHASE I

2 AUGUST 1978 MDC-E1920

# FINAL REPORT

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## ABSTRACT

The purpose of the present three year study is to identify the variables affecting FLIR target acquisition and to provide quantitative data on operator performance within the context of an aircraft attack mission. With a FLIR system, changes in display luminance represent changes in the level of emitted thermal energy received by the sensor. Perceptually, the situation is novel and complex as these heat differences are not visible to the naked eye, and generally, the observer has no prior experience evaluating them. Defining this basic research on FLIR target acquisition within the boundary conditions set up by the operational utilization of FLIR systems, will allow the data generated on perceptual processes to be directly applied to system design engineering, as well as providing target acquisition information for FLIR systems.

The first year was devoted to outlining a realistic mission scenario, the development of specifications of a state-of-the-art FLIR sensor, a review of the pertinent literature to identify the significant variables affecting acquisition, and the definition of a study program on basic perceptual processes which have application to the operational world. The execution of the experimental plan developed and outlined in this report will make up the bulk of our second year effort. The third year will be devoted to further experimentation and analysis of perceptual problems which will be determined by the results of the previous effort.

Our review of the operational variables considered the nature of the target, the deployment of the opposing forces, and the environmental constraints imposed on the mission by weather and terrain. The FLIR sensor review defined the critical parameters of an advanced FLIR system with respect to system resolution, sensitivity, field-of-view, and S/N ratio. These areas were integrated to specify a mission scenario typical of the operational theater and within the target acquisition capability of the sensor.

From this analysis we identified the stabilized image display configuration as the one most applicable to the acquisition of small tactical targets. This configuration tracks an area on the ground, and as the sensor closes with the

area, the image scale increases as though the system was "zooming-in" on the target. The unique dynamics of this system present a perceptually complex and consistently changing image to the observer. On the basis of both the need for operationally applicable data on FLIR target acquisition capability and the fundamental problems in perceptual processes under these conditions of image dynamics, it was decided to concentrate the research efforts on studying the observer's target acquisition performance using a stabilized image system.

To aid in the selection of our study variables a literature review was conducted. Scene, target, environmental, and aircraft flight parameters were evaluated to determine their potential for effecting target acquisition performance and a list of those factors making significant contributions to performance was generated. This list was then integrated with the mission scenario and the sensor capability to identify the major factors influencing target acquisition performance in an operational context. A study was configured to investigate these variables within the boundary conditions set by the mission scenario. In this study a $3^5$ factorial design will be used to obtain performance measures on the effects of starting range, rate of closure with the target, target type and signature, and background scene complexity. These data will serve as a baseline against which to evaluate additional variables affecting the target acquisition process. Further studies utilizing these variables will be identified as part of the Phase II effort.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

# 1.0 INTRODUCTION AND OVERVIEW

One of the most immediate and demanding requirements facing tactical aviation is an operationally viable, day/night attack capability against mobile, tank-size targets operating within heavily defended battle zones.

One of the most promising techniques for meeting these requirements is forward-looking infrared (FLIR) sensor systems. Not only do these sensors operate at night, but they can acquire small, thermally active or reflective targets during daylight hours. Since the early development of FLIR systems in the mid-1960s, technology trends have been toward smaller and less expensive systems for aircraft and missile applications. Early FLIR systems were predominantly of parallel-scan configuration[1], while more recent systems have tended towards a serial or serial/parallel combination employing fewer detectors but providing higher signal-to-noise (S/N) ratios by temporal integration of signals from several detectors. FLIR systems of this type have been incorporated into airborne target acquisition systems for tactical aircraft (TRAM and PAVE TACK[1]), remotely piloted vehicles (RPVs), and guided munitions (IR MAVERICK and IR-GBU-15[1]) (Ory, Schaffer, Jaeger and Kishel, 1975). These systems typically use a hot spot tracker, but because of their limited resolution capability, difficulty is encountered identifying small tactical targets. The new generation FLIRs have a resolution capability competitive with TV and low light level TV systems and can provide a high resolution real-time sensor for target discrimination.

Typically, FLIR sensor outputs are imaged on a cathode ray tube (CRT) display mounted in an aircraft cockpit. An observer views the FLIR image and reacts to targets as they appear. The observer's capability to acquire the target, given an IR target signature, is a critical factor in the successful utilization of FLIR as an air-to-ground target acquisition system.

Considerable research has been conducted concerning the observer's capability to acquire targets imaged on a CRT display. These studies, (Erickson, 1964; Jones, Freitag and Collyer, 1974; Krebs and Lorence, 1974) however, have dealt

[1]See Glossary.

almost exclusively with TV sensors operating in the visible spectrum. FLIR sensors usually include mercury-cadmium telluride detectors with peak sensitivity in the 8-14 micron spectral region which produce a unique image, especially with respect to thermally active targets. With a FLIR system, the observer sees a pictorial representation of the target which, while having a similarity to an image based on the visual spectrum, presents a different type of information. A FLIR system produces display brightness by sensing emitted thermal energy instead of reflected light. Perceptually, the situation is complex as these heat differences are not visible to the naked eye, and, generally, the observer has no prior experience evaluating them.

The target background will also appear different on an IR imager. The target to background contrast obtained with IR imagery is, in many cases, higher than that obtained with TV imagery. The polarity of this contrast can also change with the time of day, a warm target showing brighter than a cool background during the late afternoon and the same target showing darker than the background towards dawn because of cooling during the night.

The preceding review suggests that while the utilization of a FLIR sensor can extend the visual acquisition range and provide a night capability, it presents a new array of perceptual problems. The pilot or systems operator must achieve target acquisition from a displayed image of an infrared representation of the real world.

Evaluating these sensors with respect to their use in the real world also presents problems with respect to the sensor format and imagery dynamics. A real world system must acquire the target well in front of the aircraft to allow for weapon set up and delivery. The scene must also be imaged at a scale and resolution which will allow the observer to find the target. This requires the use of a narrow field-of-view sensor. In addition, the area imaged on the display is in motion. The specific type and rate of motion depends on the configuration of the sensor and the aircraft speed. A number of laboratory studies (Bruns, Wherry and Bittner, 1970; Bruns, Bittner, and Stevenson, 1972; Levine and Youngling, 1973) have been conducted to evaluate the effects of sensor and display dynamics on target acquisition but they have not considered many of the problems, particularly the FLIR signatures, nor has this basic research considered the operator's requirements with respect to an aircraft attack envelope.

The purpose of the present three year study is to identify the variables affecting FLIR target acquisition and to provide quantitative data on operator performance within the context of an aircraft attack mission. To accomplish this the first year was devoted to outlining a realistic mission scenario, the development of specifications of a state-of-the-art FLIR sensor, a review of the pertinent literature to identify the significant variables affecting acquisition and the definition of a study program on basic perceptual processes which have application to the operational world (see Figure 1). The execution of the experimental plan developed and outlined in this report will make up the bulk of our second year effort. The third year will be devoted to further experimentation and analysis of perceptual problems which will be determined by the results of the year two study.

Our review of the operational variables considered the nature of the target, the deployment of the opposing forces, and the environmental constraints imposed on the mission by weather and terrain. The FLIR sensor review defined the critical parameters of an advanced FLIR system with respect to system resolution, sensitivity, field-of-view, and S/N ratio. These areas were integrated to specify a mission scenario typical of the operational theater and within the target acquisition capability of the sensor.

From this analysis we identified the stabilized image display configuration as the one most applicable to the acquisition of small tactical targets. This configuration tracks an area on the ground and as a sensor closes with the area, the image scale increases as though the system was "zooming-in" on the target. The unique dynamics of this system present a perceptually complex and consistently changing image to the observer. On the basis of both the need for operationally applicable data on target acquisition capability and the fundamental problems in perceptual processes under these conditions of image dynamics, it was decided to concentrate the research efforts on studying the observer's target acquisition performance using a stabilized image system.

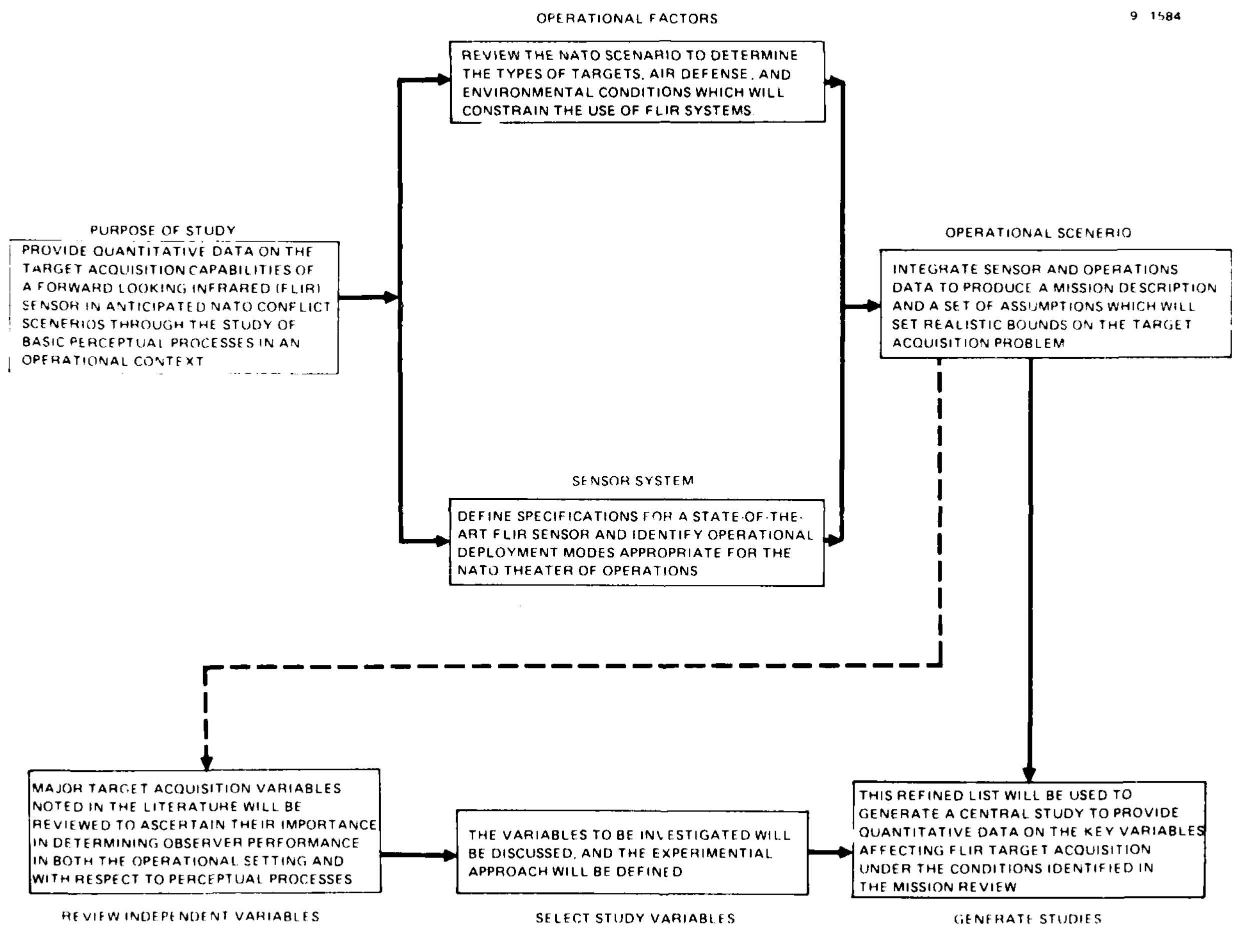


FIGURE 1 OUTLINE OF THE PHASE I STUDY EFFORT

To aid in the selection of our study variables a literature review was conducted. Scene, target, environmental, and aircraft flight parameters were evaluated to determine their potential for affecting target acquisition performance and a list of those factors making significant contributions to performance was generated. This list was then integrated with the mission scenario and the sensor capability to identify the major factors influencing target acquisition performance. A study was configured to investigate these variables within the boundary conditions set by the mission scenario. In this study a $3^5$ factorial design will be used to obtain performance measures on the effects of starting range, rate of closure to the target, target type and signature, and background scene complexity. These data will serve as a baseline against which to evaluate additional variables affecting the target acquisition process. Further studies utilizing those variables will be identified as part of the Phase II effort.

The Phase I effort has yielded a study program of basic perceptual processes for Phase II, designed to quantify the effects of the major parameters affecting acquisition performance. These empirically generated values will provide basic design engineering guidelines for future FLIR systems, inputs for target acquisition model validation, and information on the training and decision processes inherent in the acquisition task.

# 2.0 OPERATIONAL FACTORS

In order to evaluate the operator's target acquisition capabilities using a FLIR sensor system, it is first necessary to establish both the proposed use of the system and the conditions under which it will be deployed. For the purpose of this study, we are postulating a NATO or Central European environment. This section reviews the threat within this theater of operations and selects representative targets for use in the study. Enemy air defense is also evaluated to determine its impact on the mission profiles. Geographically, the NATO scenario presents a difficult target acquisition environment with a large variety of man-made features and a wide range of weather and terrain conditions. The constraints that weather and terrain impose on the mission flight profiles will also be evaluated, and tentative profile boundaries will be established.

## 2.1 TARGET SELECTION

In an analysis of the success or failure of past air strike campaigns from WW II through the Six Day War (see Figure 2), Beatty (1973) derived a generic description of target categories (see Figure 3). As might be expected, attacks concentrated directly on targets of military potential had the highest payoff. The direct destruction of war material and key production facilities, reduction in ground force mobility, and the interference with surface sea traffic were the most effective tactics. Attacks on land line-of-communication (LOC) supply routes often force the use of less efficient means of supply, such as night convoys, but seldom stop the supply flow. An exception to this occurs where signigicant choke points exist along a supply route. Interdiction of the Gadi and Mitla Passes into the eastern Sinai Desert could effectively choke off the routes from the west into that theater of operations. The target descriptions given in Figure 3 are illustrative of the targets for effective air strikes.

The defense oriented posture of our foreign policy in Central Europe limits us to a reactive strategy. In the event of war, our initial tactic must be to blunt and contain an enemy offensive, probably a massed armor and armored infantry attack. Examples of this type of attack exist in the scenarios of both the Six Day War and the more recent Yom Kippur War. Both sides in these two conflicts used the same general tactic, massed armor penetration of enemy territory, for their initial strike. During the Six Day War, the preemptive armored strike made

9–1562

| EVENT | PREDOMINANT ACTIVITIES | PRODUCT |
|---|---|---|
| WORLD WAR II | | |
| EUROPEAN THEATER | | |
| GERMAN ATTACK ON POLAND, 1939 | CF&S [1] AND INTERDICTION | SUCCESS |
| AIR OPERATIONS IN FLANDERS, 1940 | | |
| GERMAN | INTERDICTION | SUCCESS |
| UNITED KINGDOM | INTERDICTION | FAILURE |
| BATTLE OF BRITAIN, 1940 | CF&S | FAILURE |
| GERMAN ATTACK ON RUSSIA, 1941 | CF&S | SUCCESS FOR ATTACK ONLY [2] |
| ALLIED AIR OPERATIONS IN ITALY, 1944 | INTERDICTION | PARTIAL SUCCESS [3] |
| OPERATION OVERLORD, 1944 | INTERDICTION | SUCCESS |
| ALLIED BOMBARDMENT OF GERMANY, 1941–1945 | CF&S | SUCCESS [4] |
| PACIFIC THEATRE | | |
| PACIFIC CAMPAIGNS, 1942 1945 | INTERDICTION | SUCCESS [5] |
| JAPANESE HOME ISLANDS, 1945 | CF&S | SUCCESS [6] |
| KOREAN WAR | | |
| OPERATIONS STRANGLE AND SATURATE | INTERDICTION | FAILURE [7] |
| STRATEGIC | CF&S | FAILURE |
| AIRFIELD SUPPRESSION | CF&S | SUCCESS |
| NORTH VIETNAM | | |
| INTERDICTION | INTERDICTION | UNKNOWN [8] |
| STRATEGIC | CF&S | UNKNOWN |
| LAOS | INTERDICTION | UNKNOWN [9] |
| MIDEAST | | |
| SIX DAY WAR | CF&S OF AIRFIELDS | SUCCESS |
| YOM KIPPUR WAR | INTERDICTION | SUCCESS |

1 CF&S COUNTER FORCE AND STRATEGIC IN WHICH THE PREDOMINANT TARGETS WERE EITHER MILITARY (e.g., AIRFIELDS) OR ECONOMIC BASE (e.g., FACTORIES, CITIES)
2 IN LONG RUN, THE RUSSIAN AIR FORCE WAS NOT DEFEATED. IT WAS NEVER SUBJECT TO ALL OUT ATTACK
3 STRANGLE FAILED IN ITS DECLARED PURPOSE, BUT AIR OPERATIONS OF STRANGLE PLUS DIADEM WERE DECISIVE IN DEPRIVING ENEMY OF MOBILITY.
4 QUALIFIED BY SOME FAILURES (e.g., SUB PENS & BALL BEARINGS) BUT NOTABLE SUCCESSES VERSUS OIL, AND GAINING OF AIR SUPERIORITY BY JUNE 44.
5 IN CONJUNCTION WITH SURMARINES.
6 QUALIFIED BY OTHER FACTORS NOTABLY THE BLOCKADE AND MILITARY REVERSES.
7 QUALIFIED IN THAT IT MAY HAVE LIMITED CHICOM OPERATIONS
8 WE DID TRADE IT FOR NEGOTIATIONS, AND INDIVIDUAL STRIKES WERE SUCCESSFUL WHERE TARGETS AVAILABLE. MINING IN CONJUNCTION WITH OTHER STRIKES MORE SUCCESSFUL IN '72.
9 A LOT OF DAMAGE WAS DONE BUT NO PROOF EXISTS IT LIMITED OPERATIONS IN THE SOUTH. IT DID INCREASE COST TO NORTH VIETNAM & ITS ALLIES.

**FIGURE 2 CAMPAIGNS ILLUSTRATING THE SUCCESS OR FAILURE OF STRIKE OPERATIONS (FROM BEATY, 1973)**

by the Israelis was accompanied by massive air strikes against Egyptian airfields and other targets behind the forward edge of the battle area (FEBA). Because of the massive build up of air defense around target sites and along the border, a similar strike today would suffer intolerable attrition rates. The same kind of defense can be found in Europe where the Soviet block countries have raised a defensive wall of AAA around their border. However, it has been pointed out that in case of attack, they must come out from behind that wall and depend on mobile air defense systems (Furlong, 1974). Countering such an offensive will depend on our ability to neutralize their mobile air defense and destroy a significant portion of the attacking forces.

9 1563

| TARGETS OF EFFECTIVE STRIKE | TARGETS OF INEFFECTIVE STRIKE |
|---|---|
| ENEMY OFFENSIVE POTENTIAL<br>AIR FIELDS<br>SHIPS<br>TANKS | POPULATION CENTERS FOR POLITICAL ENDS<br><br>GENERAL ECONOMIC POTENTIAL |
| FACTORS AFFECTING GROUND FORCE MOBILITY<br>BRIDGES<br>TRANSPORTATION CHOKE POINTS | LAND LINES OF COMMUNICATION WHERE SIGNIFICANT CHOKE POINTS DO NOT EXIST |
| CRITICAL INDUSTRY<br>WEAPONS MANUFACTURE<br>CRITICAL COMPONENTS | |
| INTERDICTION OF SURFACE SEA TRAFFIC | |

**FIGURE 3 TARGETING STRATEGIES OF HISTORICAL EFFECTIVE AND INEFFECTIVE AIR STRIKE CAMPAIGNS (FROM BEATTY, 1973)**

An analysis of the targets encountered in the first several miles beyond the FEBA indicated that the majority of targets would consist of tanks, trucks, APCs, mobile air defense vehicles, and their associated radar vans (Mills, 1977) (see Figure 4). A list of typical targets for air strikes (see Figure 5) has many entries containing this class of mobile vehicles. These targets, therefore, are not only important in stopping or blunting an armored attack; they have the highest frequency of occurrence in the first several miles from the FEBA and make up almost half of the targets considered important for air-to-ground attack. Additionally, vehicle targets are generally considered to be at the difficult end of the target spectrum with respect to both acquisition and successful weapons launch. Based on this analysis, we plan to use selected vehicle targets as the stimuli for this study. Details of their characteristics will be discussed in Section 6.

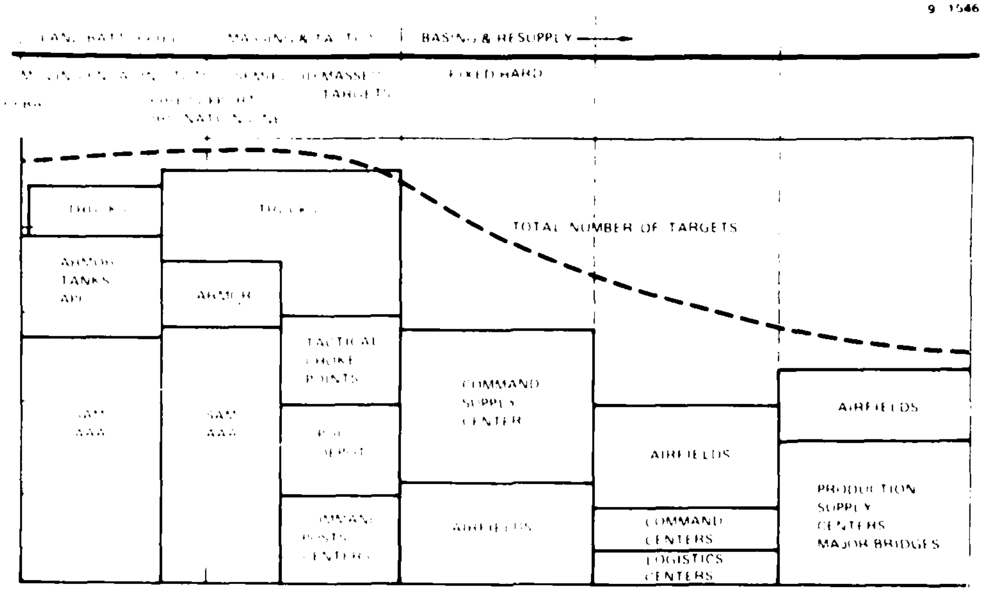


**FIGURE 4 DISTRIBUTION OF TARGETS BEHIND THE FORWARD EDGE OF THE BATTLE AREA (FROM MILLS, 1977)**

1. MOBILE SAM – ONE LAUNCHER, OR RADAR, 23x10x8 FT.
2. ARMORED COLUMN – MOVING TANKS (OR APCs) EQUALLY SPACED IN A COLUMN. EACH TANK IS 22x11x8 FT.
3. ARMORED MARCH FORMATION – TANKS AND 3 APCs MOVING IN MARCH FORMATION. EACH TANK IS 22x11x8 FT AND EACH APC IS 24x9x7 FT.
4. EW/GCI RADAR SITES – 5 REVETTED VANS IN SITE AREA. EACH VAN IS 20x8x8 FT.
5. BRIDGE-HIGHWAY – SIMPLE GIRDER 560x30x10.
6. AIR DEFENSE CONTROL CENTER/COMM. FACILITY BUILDING IS 100x90x25 FT.
7. HARDENED COMMAND AND CONTROL CENTER – HARDENED BUILDING WITH OVERBURDEN PARTLY UNDERGROUND BUNKER AND COVERED REVETMENT. BUILDING IS 70x40x20 FT.
8. AIR BASE AIRFIELD – A MAIN RUNWAY 200x8200 FT WITH A PRIMARY TAXIWAY 60x7000 FT PARALLEL TO RUNWAY IN AN AREA 9000x14,000 FT.
9. HARDENED AIRCRAFT SHELTERS – SEMICYLINDRICAL (35 FT DIA) x 64 FT WITH OVERBURDEN.
10. POL STORAGE SITE – AREA 600x500 FT WITH TANKS, EACH 24 FT HIGH BY 30 FT DIA, EQUALLY SPACED IN A 5x5 ARRAY AND SEPARATED BY 5 FT HIGH REVETMENTS.
11. FIXED SAM SITE – REVETED FIRE CONTROL AND RADAR VANS. EACH VAN IS 20x8x8 FT. EACH REVETTED AREA IS 30x16x10 FT.
12. TRANS SHIPMENT POINT – STACKS OF SUPPLIES 50x4x4 FT REVETTED AND CAMOUFLAGED, TRUCKS 22x8x9 FT EACH REVETTED.
13. BOAT CONVOY – 6 BOATS EACH 60x18x5 FT DISPERSED 1000 FT APART, AT NIGHT, CRUISING AT 15 KTS.
14. NAVAL BASE – SINGLE STORY BUILDINGS. EACH BUILDING IS 120x50x20 FT.
15. RESUPPLY COLUMN TRUCKS IN A COLUMN EACH TRUCK IS 22x8x9 FT.

**FIGURE 5 PHYSICAL DESCRIPTION AND SIZE OF TYPICAL TACTICAL TARGETS**

## 2.2 AIR DEFENSE

Air defense has evolved from optically guided AAA to radar and IR-guided weapons covering most of the aircraft attack flight envelopes. Systems now exist which can track low flying aircraft at speeds up to Mach 3 (Meller, 1977) and have target detection to weapons release times of under four seconds. To assure survivability against these air defense systems requires the optimization of attack tactics, the introduction of new weapons concepts, air-defense counter-measures, and effective crew training. The current inventory of air defense weapons held by the Soviet Block is summarized in Figure 6. This figure is based on unclassified data sources and meant to be representative rather than definitive of weapons capability. In recent years, Soviet air defense has concentrated on vehicle mounted mobile systems with a low altitude capability. The effectiveness of this strategy was shown during the Yom Kippur War where significant losses due to low level air defense were taken by the Israelis. The more modern SA-6 and SA-7 missiles accounted for most of the surface-to-air missile kills. Early reports attributed great success to the SA-6 (International Defense Review, 1973); however, later analysis indicated that of the aircraft lost to surface-to-air defense, 42 percent were lost to missiles (SA-7) and (SA-6), and 58 percent were lost to the tank mounted ZSU-23-4 AAA (Meller, 1975).

MISSILE SYSTEMS

| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | LAUNCH MODE | YEAR NOTED |
|---|---|---|---|---|---|---|---|
| [illegible] | | | | [illegible] | [illegible] | FIXED SITE | [illegible] |
| [illegible] | | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | | | | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | | [illegible] | | [illegible] | [illegible] | MOBILE LAUNCHER | 1964 |
| [illegible] | | | | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | | | | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | | | | | [illegible] | MOBILE LAUNCHER | [illegible] |
| [illegible] | | | | | [illegible] | [illegible] | [illegible] |

ANTI AIRCRAFT ARTILLERY

| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | CONTROL | DEPLOYMENT |
|---|---|---|---|---|---|---|---|
| [illegible] | | | [illegible] | [illegible] | [illegible] | RADAR | TOWED |
| | | | [illegible] | [illegible] | [illegible] | OPTICAL | SELF PROPELLED |
| | | | [illegible] | [illegible] | [illegible] | OPTICAL | TOWED |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | RADAR | SELF PROPELLED |

[illegible]

**FIGURE 6 CURRENT SOVIET GROUND-TO-AIR WEAPON SYSTEMS**

The introduction of the SA-8 and SA-9 into the Soviet air defense inventory poses additional problems in defining a safe attack envelope. The SA-8 is meant to provide a mobile, all-weather air defense capability against low level air attacks. It fills in the gaps in the air defense coverage of the ZSU-23-4, SA-6. SA-7 and SA-9 (International Defense Review, 1975). The SA-9 is essentially an improved SA-7 mounted on a mobile launcher. It is thought to use the same IR seeker but has a larger war head and rocket motor and improved maneuverability. It is typically deployed with a battery of ZSU-23-4 guns (see Figure 7) where it is linked to one of the ZSU-23-4 radars for improved target acquisition. When on the move, the SA-9 operates autonomously. Both the SA-8 and SA-9 are quite new (post-1974), and most of the details concerning their capabilities are classified or unknown.

9–1544

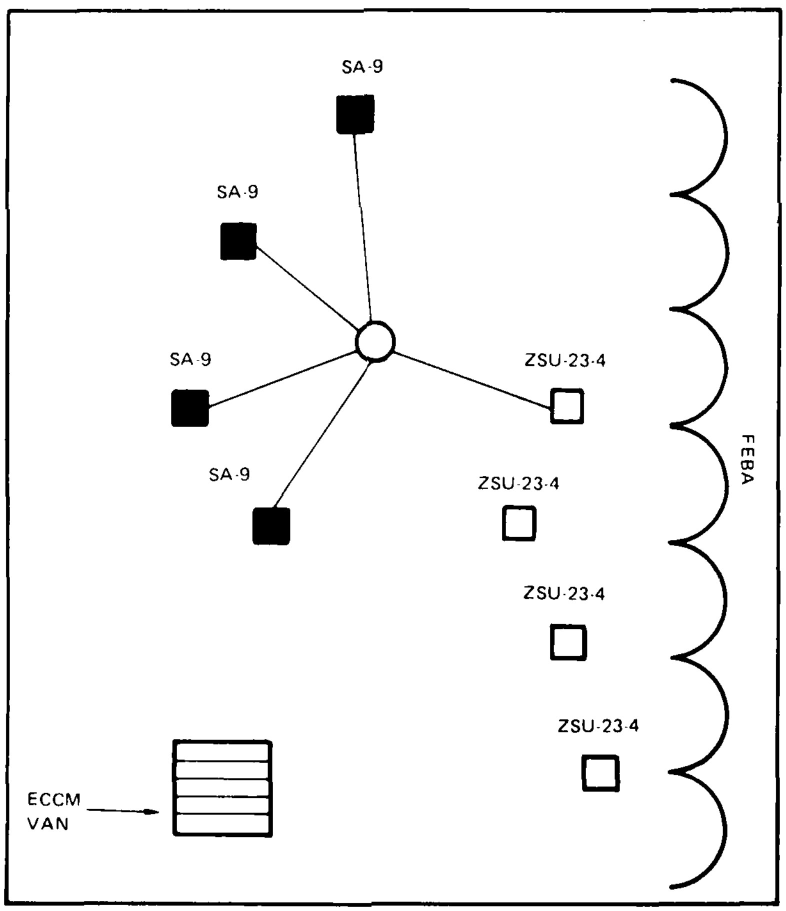


FIGURE 7 TYPICAL DEPLOYMENT OF SA-9 AND ZSU-23-4 AAA
(FROM INTERNATIONAL DEFENSE REVIEW, 1975)

An air defense barrier for conventional warfare would probably consist of a mixture of SA-3, SA-4, SA-6, SA-8, and SA-9 systems, the infantry launched SA-7 weapon system, ZSU-23-4 tank mounted AAA, and S-60 57 mm AAA. Such a barrier would have a depth of 100 km and an effective altitude of about 18,000m. The SA-4 would account for the greater horizontal coverage (70 km). The SA-3 and SA-6 provide the coverage almost to ground level. The lower altitude limits of the SA-8 and SA-9 have not been unclassified, but they are designated as low level defense systems. A composite of the air defense envelopes of a typical East European Army group is shown in Figure 8 (Meller, 1975). This defense would be bolstered by the inclusion of SA-8 and SA-9 vehicle mounted missile systems and shoulder fired SA-7s.

## 2.3 ENVIRONMENTAL FACTORS

The above sections have established targets and defense possibilities that may be encountered in a full scale NATO conventional conflict. To define the mission tactics required, it is also necessary to consider the environment in which the conflict may be fought. A number of factors inherent to the specific theater of operations can affect the success of tactics available for air-to-ground attack. The two most significant of these are the terrain and the weather. The terrain sets a lower boundary on the altitude (for a given range) at which a line-of-sight can be established between the aircraft and the target. This effect is called terrain masking and is illustrated in Figure 9. Given an absolutely smooth terrain, the curvature of the earth provides masking by the horizon at a rate of about one foot in height per every thousand feet of range. Thus, at a range of 10 miles, an aircraft would have to fly at an altitude of 60 feet or higher for the entire eight-foot high tank to be above the horizon. Land areas with this degree of smoothness are quite rare, and tactical altitudes must, therefore, be considerably higher to assure the unmasking of the target at acceptable ranges. A plot of unmasking ranges for terrains of various slopes is given in

9-1543

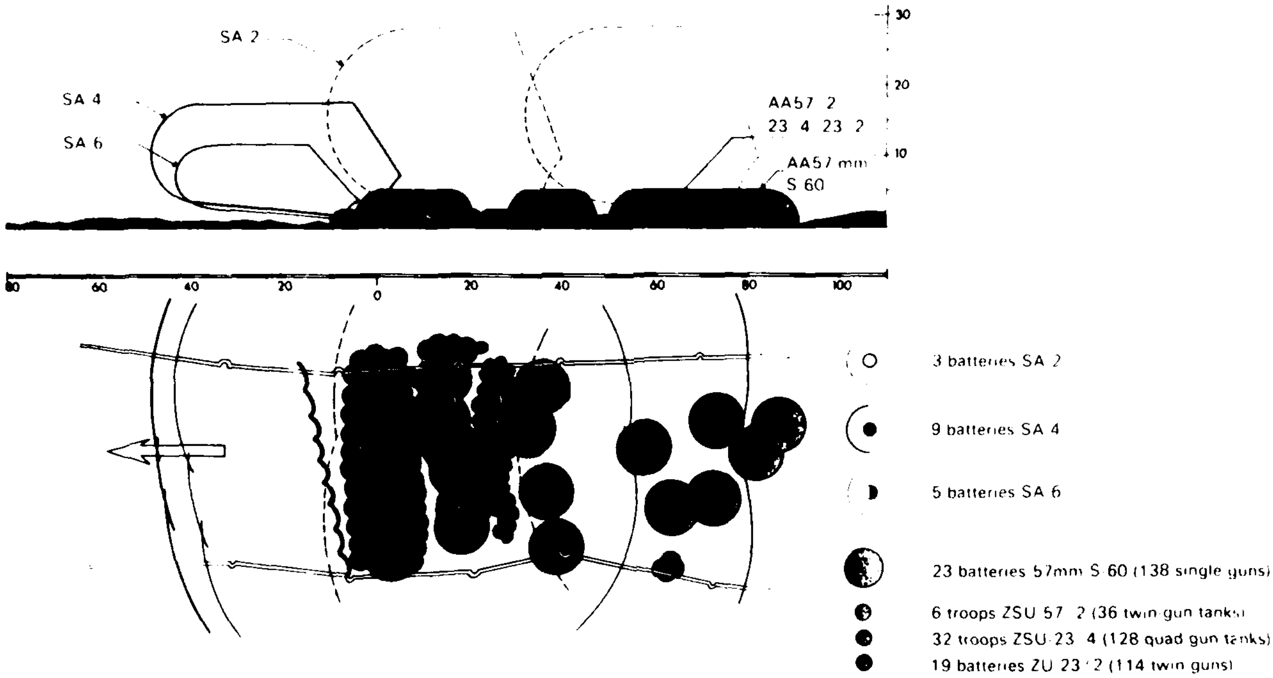


FIGURE 8 DEPLOYMENT OF AIR DEFENSE FOR TYPICAL EAST EUROPEAN SCENARIO (FROM FM 100-5, 1976)

9-1542

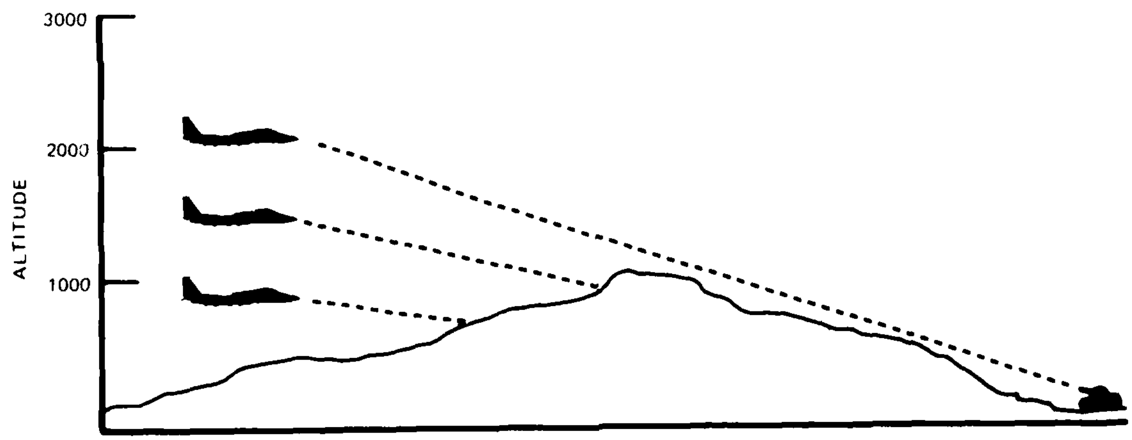


FIGURE 9 TERRAIN MASKING AS A FUNCTION OF ALTITUDE

Figure 10. This plot is for a 90 percent probability of unmasking, given the average slopes listed on the graph.[2]

The unmask range for a specific location will vary drastically as a function of the local terrain and the target placement. An evaluation of target unmask data obtained in an area of rolling hills indicated that significant masking occurred although the average terrain slope was only 0.88 degrees. Figure 11 indicates that at altitudes of 2000 to 3000 feet, the probability of unmask is reduced by 15 percent as the range approaches 15,000 feet. These observed data show significantly greater effects than the theoretical range/altitude values predicted from the relationship shown in Figure 10. This, in part, is caused by the presence of local masking caused by trees and other obstructions. Another analysis of terrain masking summarized the data for 60 sites in Britain (Erickson, 1976). The data showed that to achieve a high probability of unmask (90 percent or greater) at a 15,000 to 20,000 foot range, altitudes of 2000 to 3000 feet were required (Figure 12). Overall the results of these studies indicate that at 15,000 to 20,000 foot ranges the minimum altitude to assure a clear line-of-sight to the target should be above 3000 feet.

Weather also places constraints on an air-to-ground strike. Cloud cover, rain, fog, and other severe weather states will affect the probability of having conditions acceptable for strike. The ceiling will effectively place an upper boundary condition on the operational altitude for electro-optical sensors.

In general, the climate in Central Europe is similar to that of the inland areas of New England during the warmer half of the year and like that of the

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[2] Average terrain slope is calculated by the equation:

$$\text{Average slope} = \frac{(S_n/D_n)}{D_t}$$

$S_n$ = the slopes of the terrain in degrees from the horizontal
$D_n$ = the horizontal distances through which the terrain has the slopes $S_n$
$D_t$ = the total length of the section (in the same units as $D_n$)

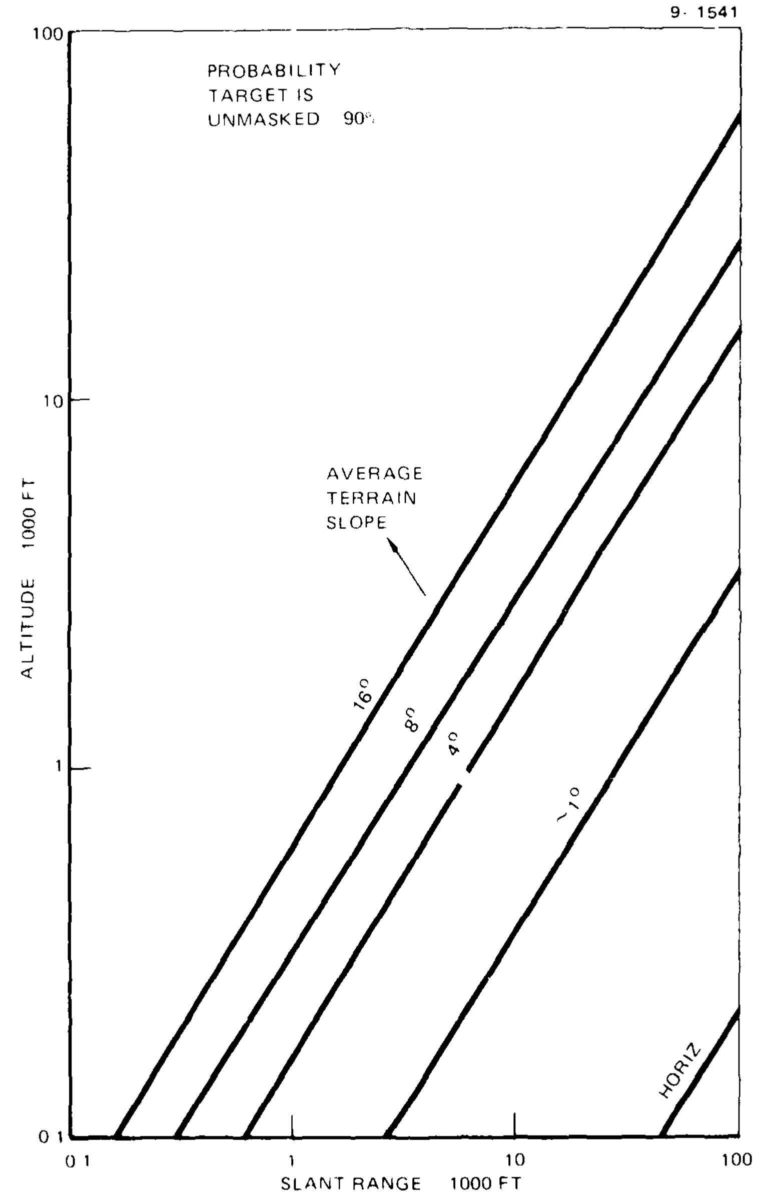



FIGURE 10 THEORETICAL SLANT RANGE TO UNMASK AS A FUNCTION OF ALTITUDE

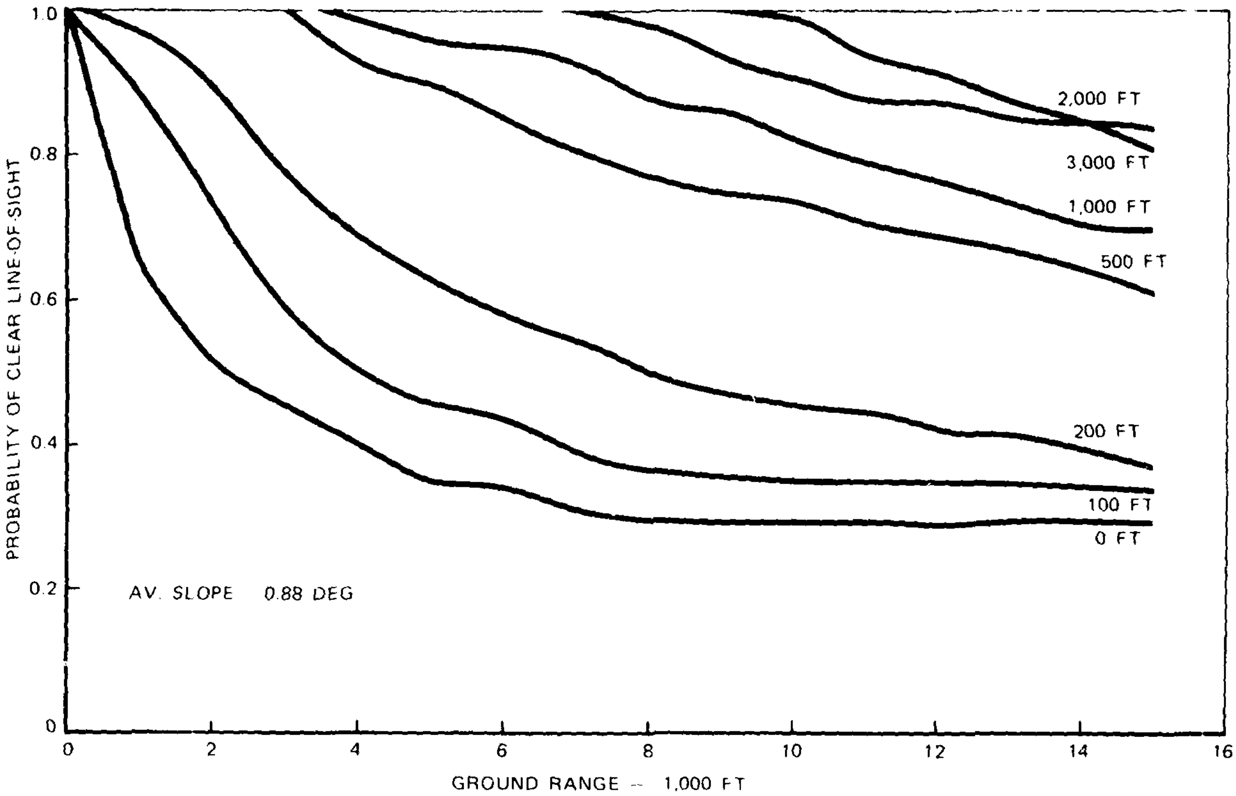



FIGURE 11 COMBINED DATA FOR SIX TARGETS IN CONTINENTAL USA
(FROM BURGE & STOHLER , 1974)

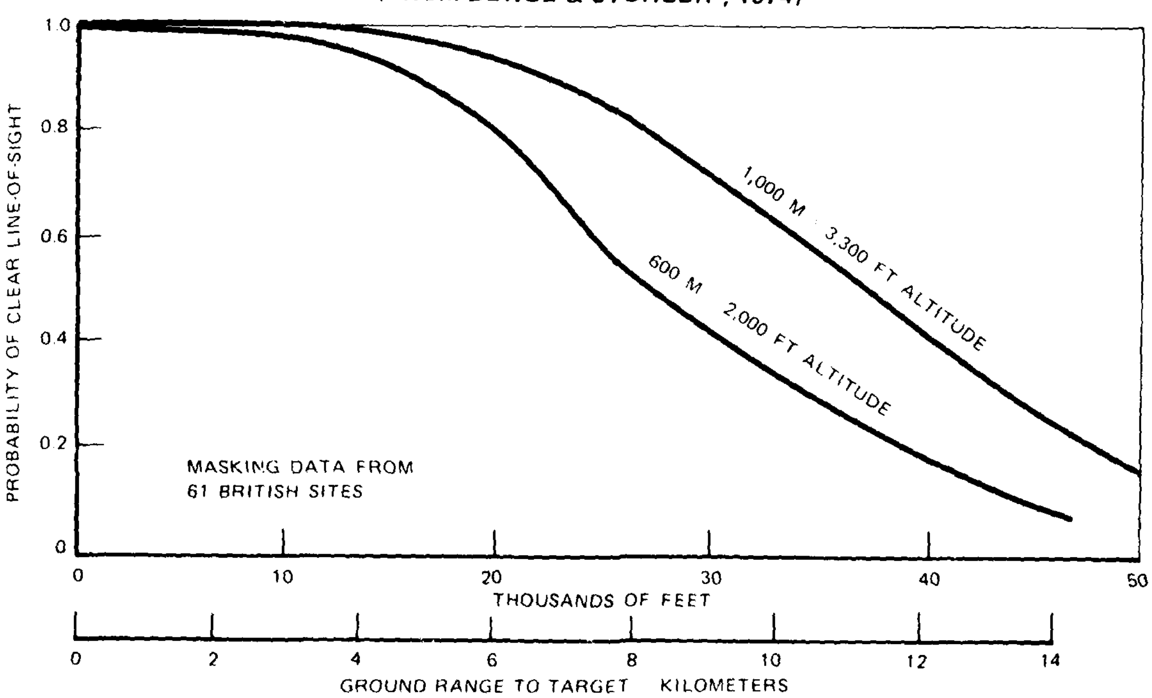



FIGURE 12 PROBABILITY OF A CLEAR LINE-OF-SIGHT TO TARGET
(FROM ERICKSON, 1976)

Pacific Northwest (west of the Cascade Mountains) during the cooler months (USAFETACIEN, 1975). Winter temperatures are moderate, but the weather is usually cloudy and stormy. There is little seasonal variation in precipitation, although rainfall is heaviest in summer. Cloudiness is at a maximum during the winter months with cloud cover normally reaching 75 percent or more 20 to 25 days a month. Annual mean cloudiness varies between 65 to 70 percent, but it can go as high as 85 percent in winter and as low as five percent in summer. Cloud cover for a Central European scenario is, therefore, a real factor in determining the upper bounds on the mission profile. The probability of having a ceiling (greater than 50 percent cloud cover) also varies as a function of altitude (Figure 13),with the lower altitudes having a greater probability of a clear line-of-sight to the target.

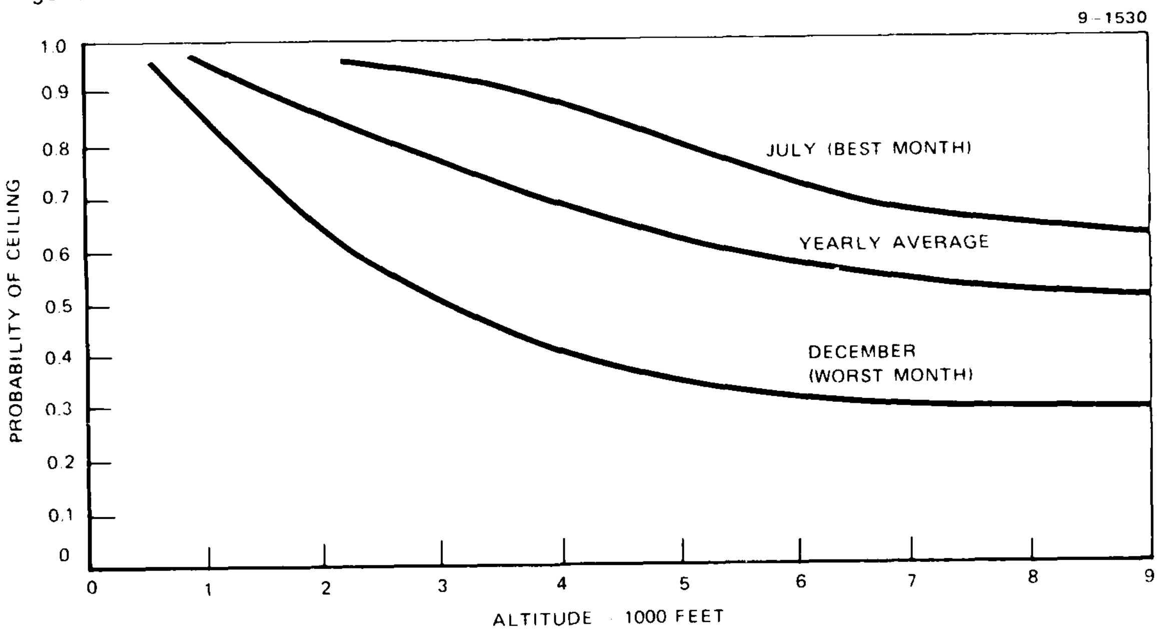



**FIGURE 13 PROBABILITY OF CEILING FOR GERMANY**

Even under the best conditions, as in July, the probability of a ceiling equal to or greater than 5000 feet is only 80 percent. Under the worst conditions, as in December, this drops to 35 percent. A 3000 foot ceiling is available 76 percent of the time averaged over the year, and 50 percent of the time in the worst month. The data on terrain and ceiling conditions indicate a fairly narrow band between the upper and lower constraints on the mission altitude. This band between 2000 to 3000 feet has a high probability of being above masking terrain features and below the cloud ceiling allowing a clear line-of-sight to the target.

Weather states such as rain, fog, temperature, and humidity constrain the mission by interfering with the transmission of energy through the atmosphere. This limits the range at which a target can be imaged by the sensor. Atmospheric components attenuate and scatter the signal reducing the quality of the sensor image. These image degradation effects will be discussed in Section 5, Independent Variables.

# 3.0 FLIR SENSOR SYSTEM

Experimental and analytical studies have indicated that the quality of the image obtained by the sensor system is a strong determiner of target acquisition. This section will define a state-of-the-art FLIR sensor/display system to determine the display image quality. These data will then be used to circumscribe a flight envelope within which the sensor system can effectively acquire the selected targets. The deployment of the sensor relative to the aircraft path also will be analyzed to identify the problems in sensor geometry and to select the most effective means of utilizing FLIR sensors to acquire tactical targets.

## 3.1 FLIR SYSTEMS

This discussion will be restricted to the display/imaging aspects of the FLIR system and assumes that the associated gimballing mechanisms, controls, windows, power supplies, support structure, and cooling/ heating are all adequate for efficient operation of the sensor.

The fundamental components of a FLIR are shown in Figure 14. These include the optics, the detectors and amplifiers, the scan converters (if applicable), and the display. How well a given system performs in a tactical situation is a function of the target/background conditions, the atmosphere, altitude, and range to the target, all of which can combine in myriad ways to produce equivalent images. Rather than consider all of the combinations, our approach will be to analyze a series of object targets and backgrounds with known angular relationships to the FLIR and determine FLIR performance as a function of the image on the display, i.e., the MRT (minimum resolvable temperature) versus angular resolution curves. Particular target, atmospheric, or geometric conditions can then be defined and related to the MRT curves to predict performance.

The FLIR is only one of several applications of infrared (IR) energy detection. A good review of the entire military applications of IR is given in Hudson and Hudson (1975). Many IR sensing applications stop with the detection of IR energy from a target, e.g., missile guidance target seekers and ICBM launch detectors. FLIRs have utility for detection, but their forte is imaging the target and surrounding scene so that more complex target recognition and identification tasks can be performed. Early FLIRs produced moderately good image quality

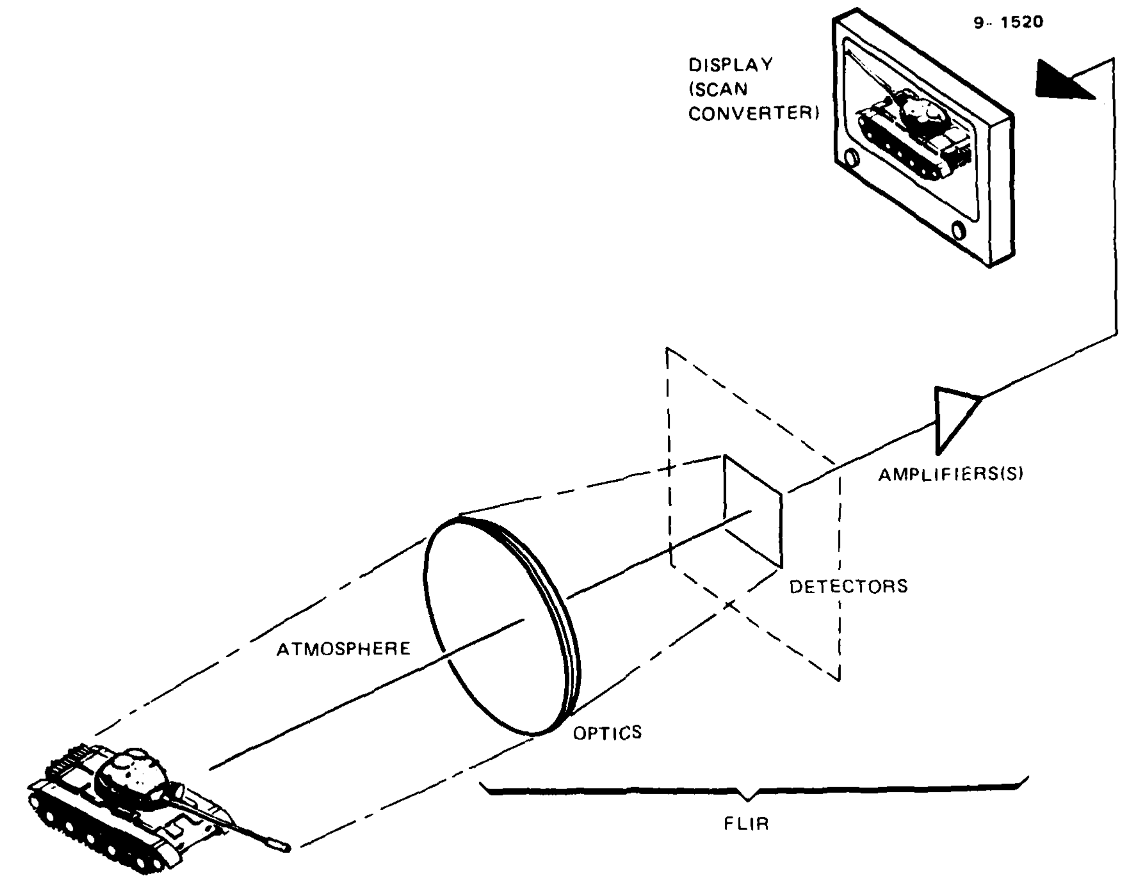



FIGURE 14 TARGET SENSING

accompanied by problems of limited dynamic range (signal to noise ratio (SNR) and contrast), angular resolution, and image blemishes such as streaks, shading, and flicker.

From an image quality or observer utility view point current and "advanced" FLIRs have higher resolution and sensitivity. The truly advanced FLIRs will have slightly smaller apertures and reduced weight, size, and costs. The major part of these advances will most likely be accomplished through focal plane arrays of detectors, charge coupled device readout techniques for the video preamplifiers. Future systems will have response capability in both the 3-5 μm region as well as the 8-14 μm region of the spectrum.

The net result, however, remains that using a closed circuit TV system is a very reasonable simulation of good quality FLIR imagery as long as correction is made for the target signature pecularities observed with IR radiation. Available display technology suggests that only CRT displays are immediately applicable to satisfy the resolution, dynamic range and brightness requirements of these sensors.

The system under consideration for this study is representative of an advanced state-of-the-art FLIR using the 8-14 $\mu$m region. This region was selected over the 3-5 $\mu$m region because of its greater sensitivity for detecting hot targets such as gun barrels. The alternative use of a 3-5 $\mu$m FLIR should have no "unusual" effect on image quality even though the signature will change slightly, and the effect of reflected solar energy will be significant when calculating energy levels.

This system has been defined in terms of the parameters and format developed for the Night Vision Laboratory (NVL)[3] FLIR target acquisition model. The purpose of this was twofold: it provided a common format for describing our system and allowed us to use the model to make trade-off studies relative to certain of the system parameters.

The descriptors of the FLIR and display to be simulated are given in Figure 15. For several of the parameters, multiple values are given which will be evaluated using the NVL model to determine performance sensitivity to those parameters. The value given for D*, background limited infrared photoconductor (BLIP), means that the noise contribution from the detection process due to the photoconductor alone is insignificant compared to the natural variance, or statistical distribution, in the arrival of photons on the detector. The magnification relates the angular field-of-view (FOV) in object space to the angular subtense of the display in the observer's perceptual space. Thus, the magnification accounts for the effects of observing viewing distance and display size in terms of display visual angle.

The diameter is the clear, circular, effective aperture of the system. The optical transmission is the ratio of radiation entering the aperture and the radiation exiting the final optical element. The radiation wavelength is an

[3] NVL is now Night Vision and Electro-Optical Labs.

9–1572

| | |
|---|---|
| OPTICS – | |
| DIAMETER | 8 INCHES |
| F-NUMBER | 5, 3.75, 2.5 |
| FOCAL LENGTH | 40, 30, 20 INCHES |
| OPTICAL TRANSMISSION | 0.7 |
| RADIATION WAVELENGTH | 10.25 μm |
| DETECTOR ELEMENTS – | |
| IFOV | 0.05, 0.075, 0.1 MRAD |
| NUMBER OF DETECTORS | 250 PARALLEL X 50 SERIAL<br>1000 PARALLEL X 10 SERIAL |
| DETECTOR SIZE | 0.002 INCH |
| PEAK D* | BLIP |
| SCANNER – | |
| FRAME RATE | 30 FRAMES/SEC |
| SCAN EFFICIENCY | 80 PERCENT |
| OVERSCAN RATIO | 1.45 |
| ELECTRONICS – | |
| FREQUENCY RESPONSE | 3.0 Hz TO 3.0 MHz |
| DISPLAY – | |
| LINES | 525 LINES |
| SIZE | 6 X 6 INCHES |
| AMBIENT ILLUMINATION | 100 FT L |
| SYSTEM – | |
| FOV | 1.0 X 1.0 DEGREES |
| MAGNIFICATION | 10.6 |

FIGURE 15 FLIR/DISPLAY PARAMETERS

average used to determine the effect of aperture diffraction on the limiting resolution and contrast transfer functions. The total radiation sensitivity is approximately from 8 to 12 μm. The detectors are assumed to be a focal plane array (FPA) of 10,000 detectors designed to give a 250 line field with a 2:1 interlace providing 500 active lines per frame over the FOV. The detectors were structured in a parallel/series configuration. This configuration uses the parallel sequence of detectors to maintain resolution and the series sequence for increased sensitivity. Two configurations were evaluated, 250 parallel/40 serial and 1000 parallel/10 serial. Scan conversion was assumed where needed and the true resolution was limited by the display capability. The 525 display lines include the 480 active scan lines and the inactive scan lines used to generate the vertical retraces both on display and in the FLIR scanning mechanism. The display raster has a left to right, horizontal orientation, and shading across the display face was not significant.

The parameters for the FLIR (see Figure 15) were developed in conjunction with the Thermal Imaging Group of the Electro-Optics and Reconnaissance Branch of the Air Force Avionics Laboratory (AFAL/RWI-2) at Wright-Patterson Air Force Base. Where a range of values was suggested, either the more conservative values were used, or the factor was varied parametrically; and performance predictions were made using the NVL target acquisition model. The exception to this was the use of a 525 line display system instead of the recommended 875 line system and the use of a larger display. The former was dictated by equipment limitations in the simulator (see Section 8.0) and the latter by human factors considerations regarding observer-limited system resolution.

The NVL model in use at McDonnell Douglas has been modified to include the Lowtran B atmospheric transmission submodel and special modifications for smoke and haze. The NVL model was run using a rural aerosol and a two kilometer visibility. Temperature and humidity were set to a standard mid-latitude winter of -1.16 degrees C and 75 percent humidity. The target was 15.4 feet long by 8.8 feet wide, the size of a M113 armored personnel carrier. Background temperature was set at .1 degree C. Range was varied from 20,000 to 2000 feet with probabilities estimated every 2000 feet.

The initial runs varied focal length (40, 30, 20 inches) and target T (one and three degrees centigrade) and held the detector array to 250 parallel 40 series detectors. The F number and instantaneous FOV were varied to maintain internal consistency with the focal lengths. The model indicated that the 40 inch focal length produced consistently better recognition probabilities at both the one and three degree temperature differentials (see Figure 16). A second set of data was run to evaluate the effects of changing the detector array from 250 parallel/40 series to 1000 parallel/10 series. The model indicated that the 250/40 array yielded better recognition probabilities (see Figure 17), especially at one degree $\Delta T$, the low contrast condition. Based on the predicted results of the model, we have configured our theoretical sensor to have a 40 inch focal length and a 250 parallel/40 series detector array.

## 3.2 FLIR SYSTEM GEOMETRY

Accurate ordnance delivery and survivability are the operational factors which drive sensor/display system design. The system must achieve the acquisition

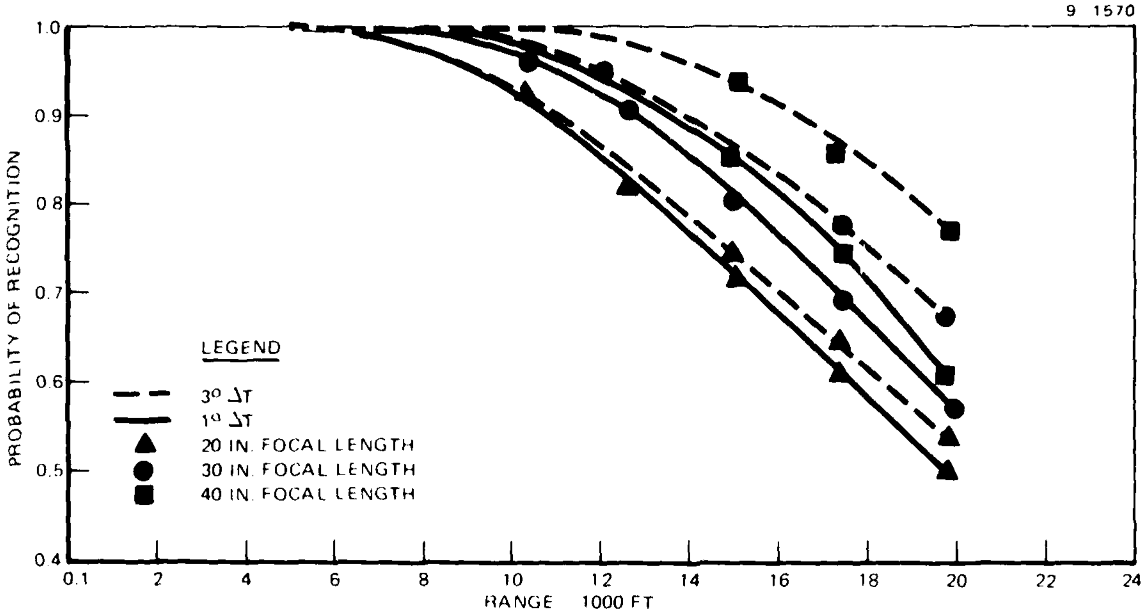



FIGURE 16 RESULTS OF MODELING SENSOR FOCAL LENGTH

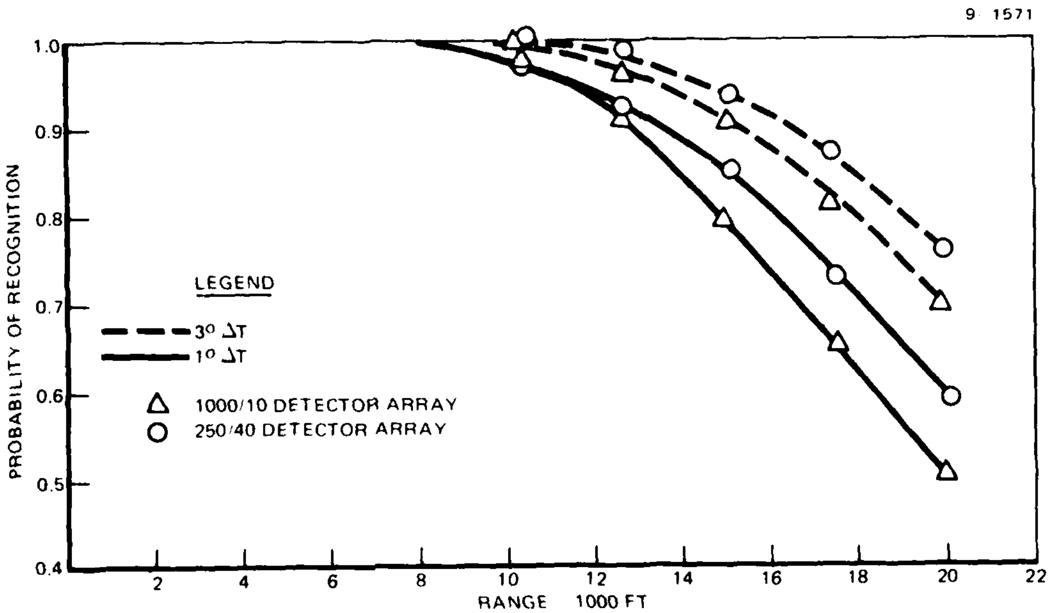



FIGURE 17 RESULTS OF MODELING DETECTOR ARRAY

of targets at speeds, altitudes, and ranges which do not compromise the survivability of the aircraft. In general, survivability is highest using a flight envelope combining minimum altitude and maximum speed and range-to-target. The sensor configuration consistent with these requirements must allow target acquisition in an area well forward of the position of the aircraft.

The area on the ground imaged by such a forward looking electro-optical sensor (the sensor footprint) is trapezoidal in shape.[4] The geometry of this sensor footprint is shown in Figure 18. Slant range (the distance from the aircraft to the center of the sensor footprint) is determined by the sensor depression angle and the aircraft altitude. The lower the altitude, the smaller the depression angle needed to reach a slant range. This relationship is shown in Figure 19.

[4] The cross track coverage at the near edge and far edge of the sensor footprint can be calculated by the formula:

$$W_N = \frac{2\ h \tan\ (B/2)}{\sin\ (\theta + a/2)}$$

$$W_F = \frac{2\ h \tan\ (B/2)}{\sin\ (\theta - a/2)}$$

The along-track dimensions of the footprint can be calculated by the formula:

$$L = \frac{h}{\tan\ (\theta - a/2)} - \frac{h}{\tan\ (\theta + a/2)}$$

where:

$W_N$; $W_F$ = near width and far width, respectively
$h$ = the aircraft altitude
$\theta$ = the depression angle
$B$ = the width of the FOV
$a$ = the height of the FOV

The ground area imaged across-track is determined by the horizontal FOV and the slant range (See 5 in Figure 18). Figure 20 illustrates the slant range/FOV/cross-track coverage relationship. Along-track coverage (See 4 in Figure 18) is determined by the vertical FOV, altitude, and the sensor depression angle (see Figure 21). This coverage increases as the field-of-view increases and decreases as the depression angle increases. At small depression angles (two to five degrees), large differences exist between the horizontal and vertical dimensions of

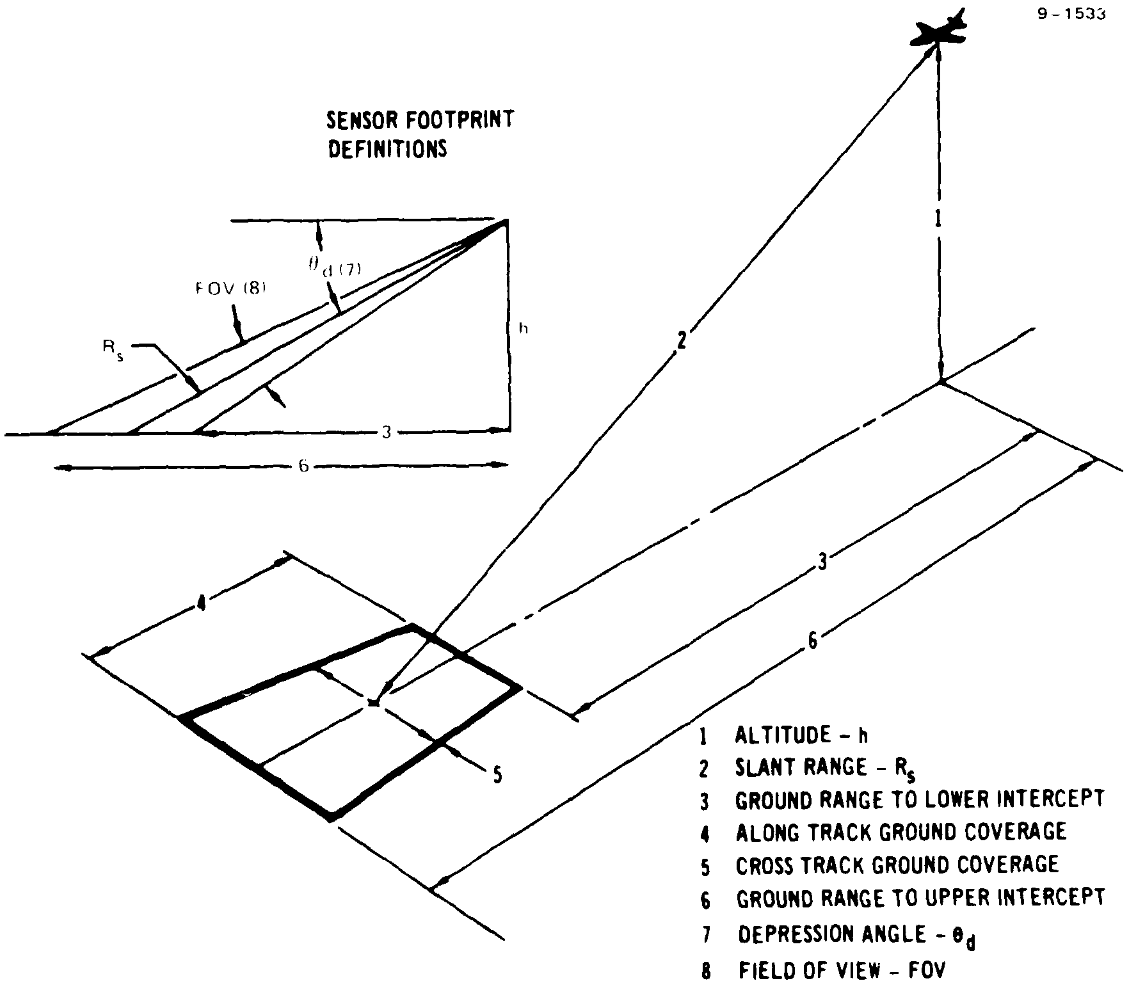



FIGURE 18 SENSOR FOOTPRINT GEOMETRY

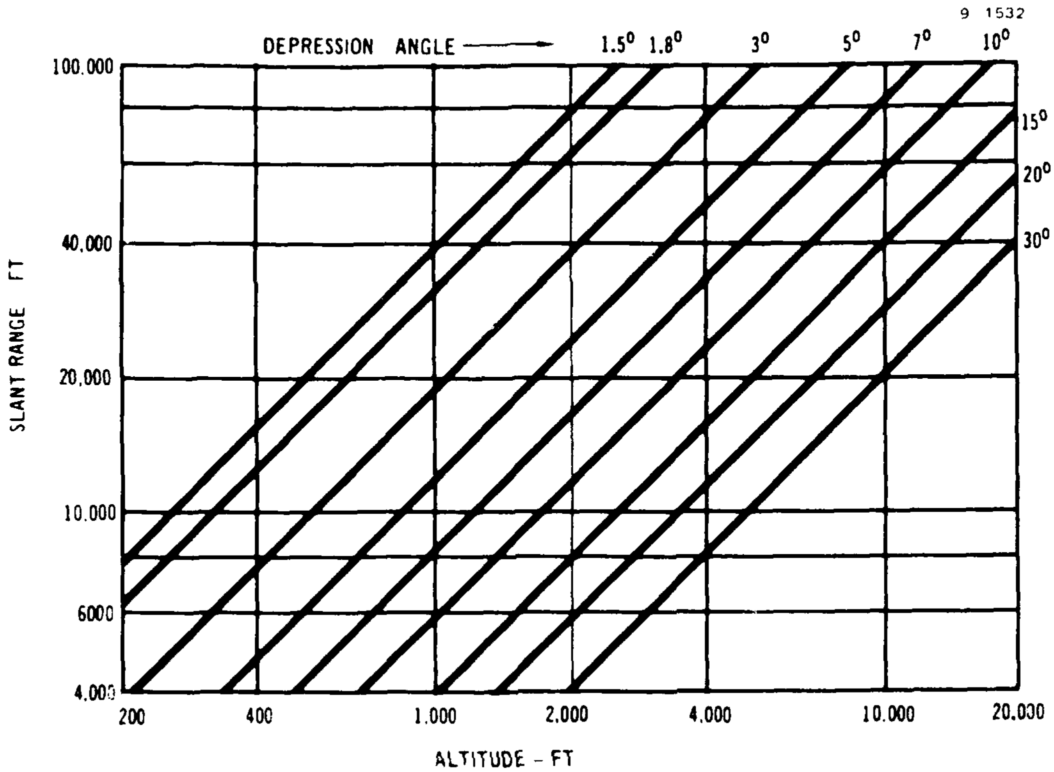



FIGURE 19 SLANT RANGE AT CENTER OF FOV

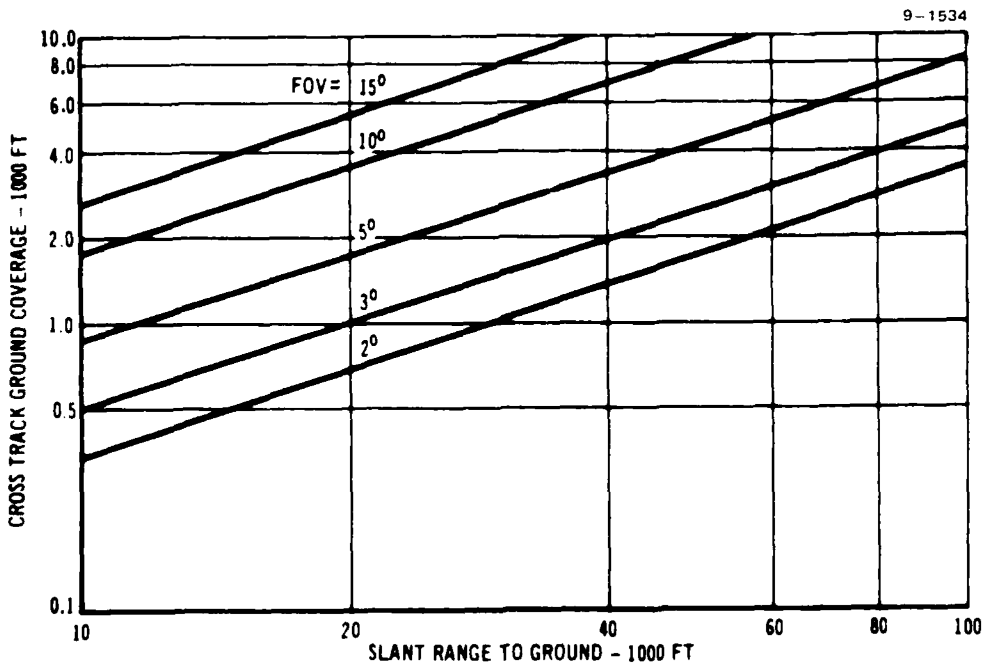



FIGURE 20 CROSS TRACK COVERAGE

the ground area on the display. For a vertical field-of-view of 2.5 degrees at a 3 degree depression angle and a 1000 foot altitude, the along-track coverage (from Figure 21) is about 20,000 feet while the cross-track coverage is slightly more than 1000 feet (assuming a 4:3 horizontal to vertical aspect ratio). As the altitude and depression angle increase, the ratio of along-track to across-track coverage decreases. For moderate depression angles, approximately 10 degrees, and altitudes over 3000 feet, the ratio of across to along-track coverage is typically 1:1.5 or less. An additional image distortion occurs as a function of the low altitude, low depression angle configuration. The differences in slant range from the front to the back of the footprint (20,000 feet in the case cited above) cause severe scale differences on the image. For the moderate depression angle 3000 foot altitude case, the slant range difference from the top to the bottom of the footprint is less severe; and scale differences typically do not exceed 10 percent.

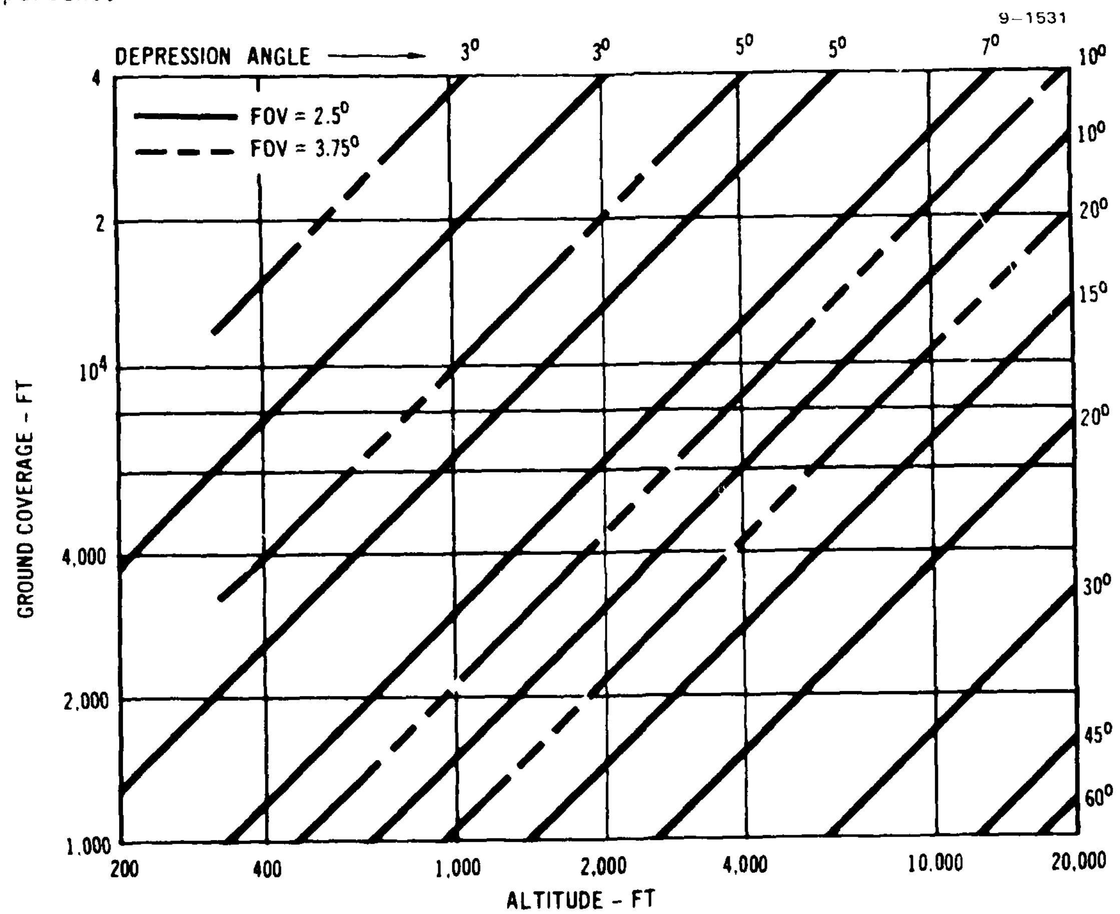



FIGURE 21 ALONG TRACK GROUND COVERAGE

3.3 FORWARD LOOKING SENSOR CONFIGURATIONS

Forward-looking sensors can either be set at a fixed depression angle or gimballed to track a point on the ground (see Figure 22). In the former case, the scene on the display will move as the aircraft travels forward giving rise to a moving window display. The rate of motion on the display is determined by the FOV of the sensor, the slant range to target, and the size of the display. The tracking sensor will present a relatively stationary image of a fixed ground area, since the sensor is gimballed to null out image motion due to aircraft flight. The size of the area imaged at a given point in time will be dependent on the FOV of the sensor, the sensor depression angle, and the distance to the target area. Assuming a fixed FOV as the sensor approaches the target, changes in the sensor/scene geometry reduce the size of the area in the sensor FOV and cause the scale

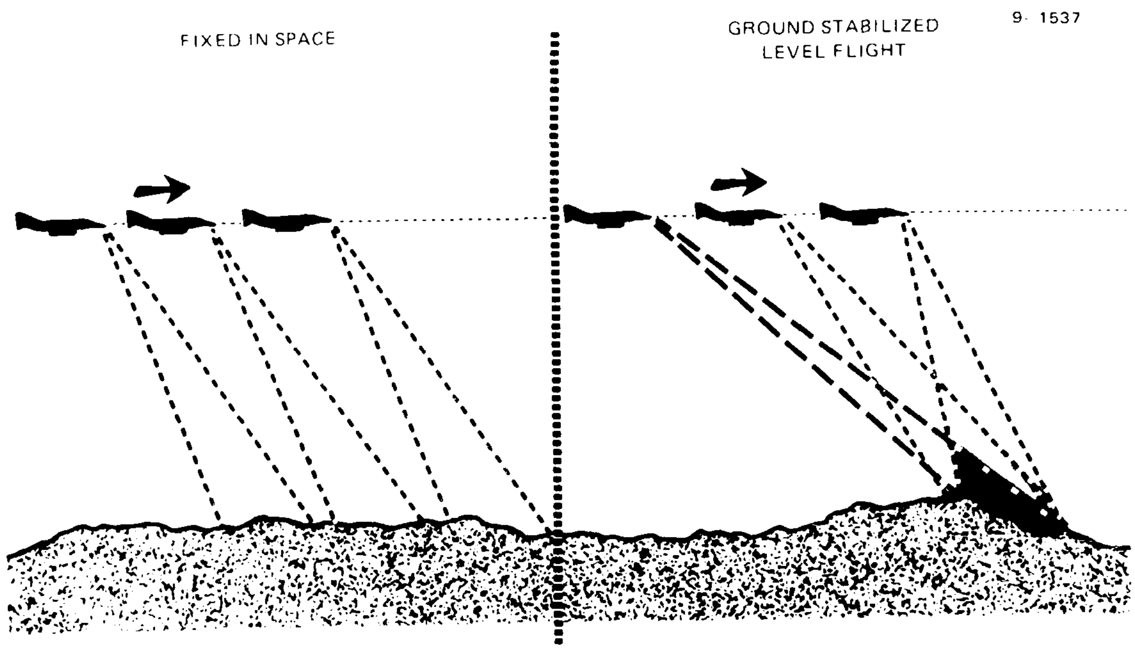



FIGURE 22 FORWARD LOOKING SENSOR MODES

of the image on the display to increase producing a "zoom" effect. In addition to the increase in scale, this zooming-in will cause targets offset from the center of the display to migrate towards the edge of the display (see Figure 23). A list of differences in display dynamics existing between these two forward-looking configurations is given in Figure 24.

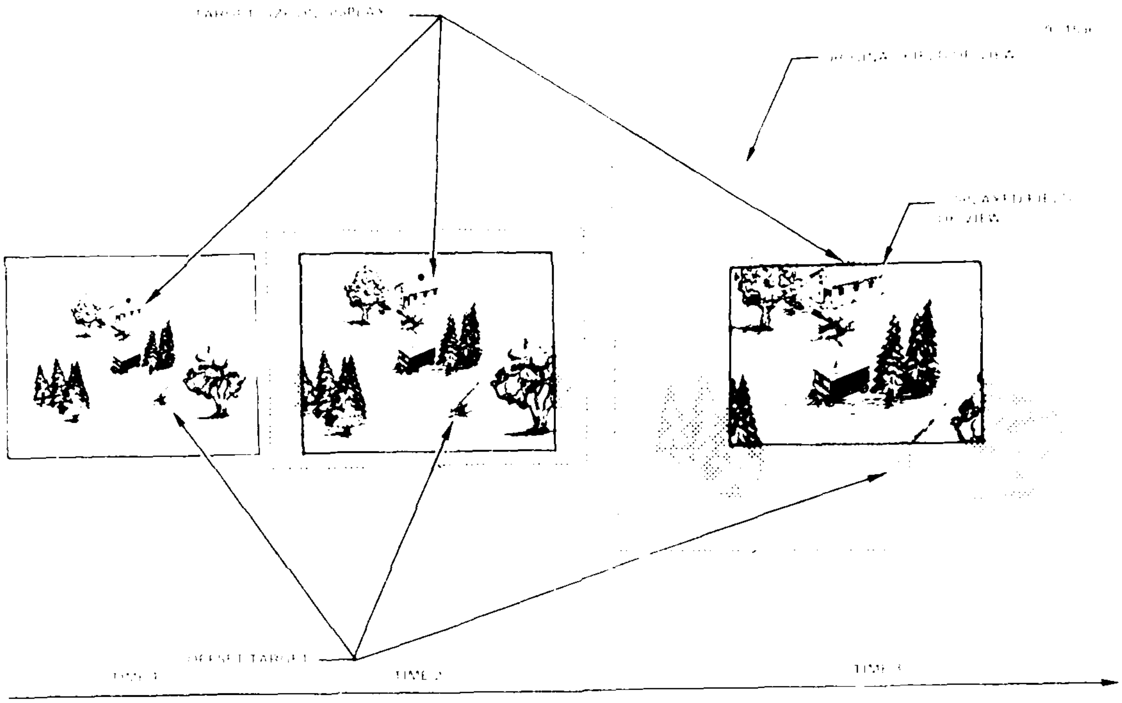


FIGURE 23 ZOOM EFFECTS WITH GROUND STABILIZED SENSOR

3.3.1 Moving Window Displays

As noted in Figure 24, moving window displays present an image which moves across the display at a speed proportional to the speed of the aircraft. The size of the display, the scale of the image, and to some extent, the speed vector of the aircraft determine the time a target will be on the display.

Analytically, this type of display presents several severe restrictions on the acquisition of small targets. Studies have indicated that targets need to subtend at least 10 to 12 minutes of arc at the eye for good acquisition (80 percent or better) (Boynton and Bush 1957; Moler 1962; Snyder and Greening 1963). Assuming a six inch high cockpit display viewed at the standard 28 inch cockpit design eye relief and a 25 foot target, it is possible to calculate the time a target will be on the display as a function of aircraft speed. Using the minimum 10 minutes of arc visual angle value, the target, when viewed at 28 inches, will be .08 inches long on the display.

9–1535

| | SENSOR GEOMETRY | |
|---|---|---|
| VARIABLE | MOVING WINDOW | ZOOM-GROUND STABILIZED IMAGE |
| IMAGE/TARGET | SCENE-TARGET MOVES ACROSS DISPLAY | FIXED SCENE/TARGET MOVES FROM CENTER TO OUTER EDGES – ZOOM EFFECT |
| TIME-ON-DISPLAY | PROPORTIONAL TO SCALE AND SPEED – RELATIVELY SHORT | DETERMINED BY RANGE, SPEED AND TARGET POSITION – RELATIVELY LONG |
| SCALE | RELATIVELY CONSTANT ACROSS IMAGE | VARIES WITH CLOSING RANGE |
| GROUND AREA TO BE SEARCHED | CHANGES CONSTANTLY AS SCENE CHANGES | GETS SMALLER AS CLOSING RANGE DECREASES |
| ASPECT ANGLE | FIXED | CAN CHANGE WITH CLOSING RANGE |

FIGURE 24 DIFFERENCES IN IMAGE DYNAMICS AS A FUNCTION OF FORWARD LOOKING SENSOR GEOMETRY

A six inch display could therefore image a ground area of 1875 feet on a side.[5] An aircraft traveling at 100 knots covers 170 feet per second. At 200 knots, the target would be on the display for only 5.5 seconds, and at 400 knots only 2.75 seconds. Independent of the effects of target motion, time-on-display of less than three to four seconds tends to degrade performance in complex search tasks (Levine and Youngling, 1973). Using the smaller value of three seconds for finding truck type targets, aircraft speeds in excess of 370 knots would produce severe degradations in performance. This speed is slightly under the loaded maximum attack speed of the A-10 aircraft (Taylor, 1977).

[4]These figures assume a square sensor footprint for ease of calculations.

Experiments conducted to evaluate the effects of this type of image motion on target acquisition tend to verify the analytical data. Levine and Youngling (1973) performed a study of TV acquisition using military targets obtained from reconnaissance imagery of Southeast Asia. Two levels of target difficulty were investigated. Based on target size, type, concealment, and background clutter, targets were divided into difficult and easy groups. The difficult targets were revetments, trench fortifications, and small truck parks and had a display size of approximately 1/5 inch. The easy targets were 3/4 inch on the display and consisted of large truck parks, forts, and fortified positions. These targets were viewed on a 5.5 inch, 3:4 aspect ratio, standard 525 line Conrac TV monitor at a scale of 1:2500. The image motion provided a total target time-on-display of 1, 2, 3, 4, 5, and 6 seconds which was equivalent to aircraft speeds of 675, 338, 227, 169, 135, and 113 knots, respectively. The results of this study are presented in Figure 25. Performance decreased as speed increased for both the hard and easy targets at motion rates greater than 1.7 inch per second. At slower rates, performance was nearly constant. The performance curves indicate that, for the display size and scale used, viewing times of less than three seconds significantly reduced performance. The three second value appears to be independent of target difficulty as the performance curves for the easy and difficult targets have the same general shape.

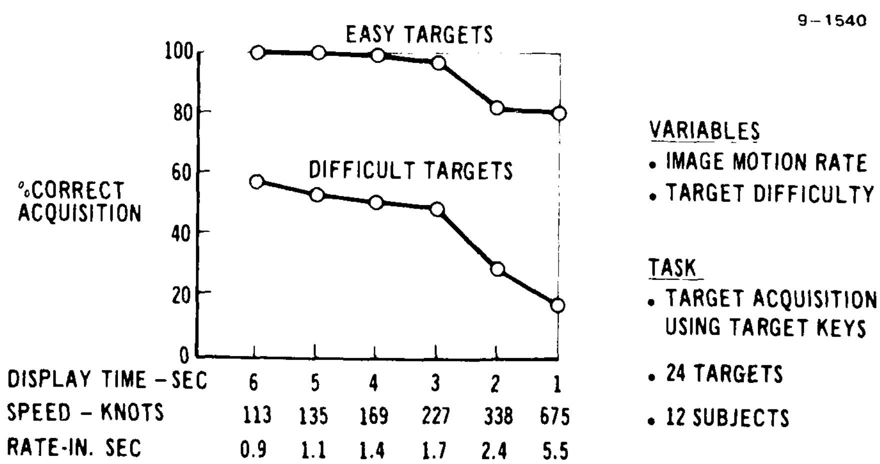
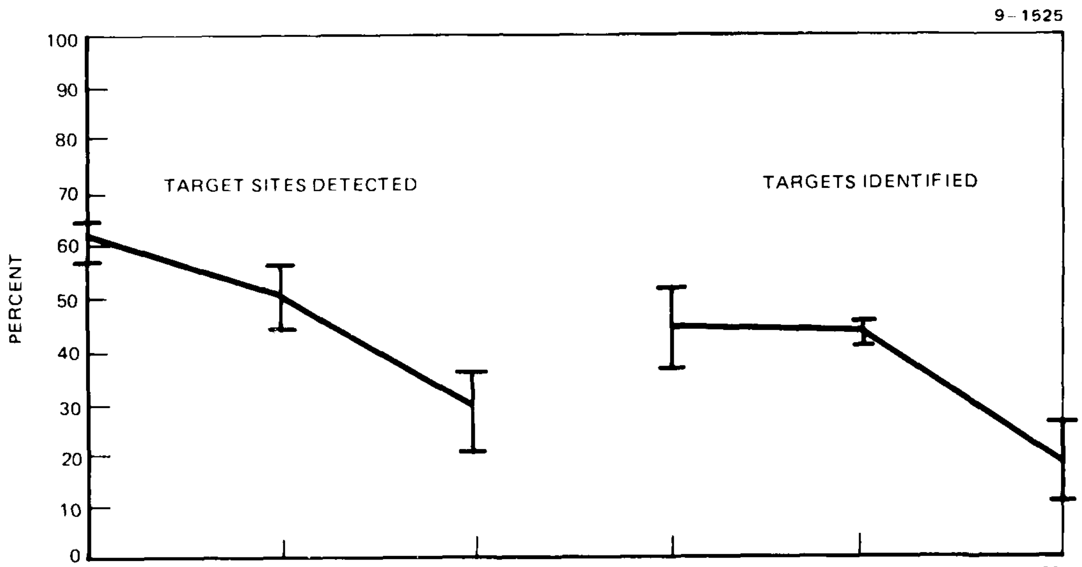



FIGURE 25 RESULTS OF MOVING WINDOW DISPLAY STUDY

In another study, Maher and Porterfield (1971) utilized active film imagery to simulate low altitude (500 to 2000 feet), low airspeed (170 knots) flight. A 20 X 20 inch rear projection screen was used to present the imagery. The study varied altitude and kept speed constant thus confounding image scale with image motion. The data indicate that target acquisition averaged about 30 percent, with the 500 and 1000 foot altitudes showing little difference in performance (see Figure 26), and the 2000 foot altitude case having significantly poorer performance. It should be noted that, for this experiment, altitude, aircraft speed (image motion), and display size were all at more favorable values for acquisition than are likely to be found with high performance aircraft in an operational setting.




| ALTITUDE IN FEET | 500 | 1000 | 2000 | 500 | 1000 | 2000 |
|---|---|---|---|---|---|---|
| MEAN PERCENT | 61.1 | 50.0 | 28.5 | 44.9 | 43.8 | 18.8 |
| STANDARD DEVIATION | 4.3 | 5.9 | 7.2 | 7.5 | 2.4 | 7.4 |

**FIGURE 26 FLIR TARGET ACQUSITION USING A MOVING WINDOW DISPLAY (FROM MAHER AND PORTERFIELD, 1971)**

### 3.3.2 Stabilized Image Display

The dynamics of a stabilized image sensor system present unique problems in system design. Although tracking a ground area eliminates image motion in the direction of flight, the system geometry produces a "zoom" effect as the aircraft closes with the calculated target location. This effect is analogous to zooming in on a scene with a camera, the scale of the image scene increases. If the target is in the center of the FOV, it will increase in scale as the aircraft closes with it. If, however, the target is offset from the center of the FOV, it will migrate towards the edge of the display as the aircraft closes. If the offset is sufficiently large, the target can go completely off the display relatively early in a run. Aircraft speed will affect the time a target is on the display, and the rate of increase in image scale as the aircraft approaches the target. These factors will have a significant effect on the system operator's ability to acquire a target and his acquisition time. Perceptually, the observer is forced to search a display in which the scene is expanding outward from the center of the screen. At the same time, the objects on the ground are imaged at a progressively larger scale. The critical question is whether the target is on the display long enough and at an adequate scale and resolution for successful target acquisition. A review of the current literature indicates little systematic investigation of these variables and how they will affect overall mission success. Research needs to be performed to investigate operator performance characteristics and to define a set of criterion data to be used as a source for evaluating the effectiveness of ground stabilized target acquisition systems. These data, while defining basic perceptual processes, will have application for FLIR ground stabilized electro-optical systems, including missile and smart bomb guidance, advanced aircraft air-to-ground weapons delivery, and high speed, real-time reconnaissance.

Investigations of stabilized image displays (Levine and Youngling, 1973) have found that offset and aircraft speed have significant effects on performance. The effects of offset, however, were limited to the outer 1/3 of the displayed area. Targets in the center 2/3 of the display yielded no difference in performance. The effects of aircraft speed were found to be linear over the range studied (360 to 1200 knots) with a 15 percent drop in performance from the slowest to fastest speeds. In another study of target acquisition on stabilized image displays (Bruns, Wherry, and Bittner, 1970), aircraft speed and target background relationships were found to be significant factors. The target background relationship was a complex factor consisting of target edge gradient, target background contrasts, and target edge complexity. These factors were scaled by a subjective judgment procedure and analyzed using regression analysis. They accounted for 22 percent of the total variance in the performance measure and 51 percent of the variance accounted for by the variables studied. In a follow-on study (Bruns, Bittner, and Stevenson, 1972), targets at a known location (one inch square in the center of the display) were acquired using a TV sensor. The study found target size and target background contrast to be significant factors for target detection, identification range, and probability of correct identification. Target background contrast was treated as a random variable and analyzed through regression techniques. It accounted for 23 percent of the detection range variances (over half of the total accounted for), and 12.5 percent of the identification range variances (about 1/4 of the total variance accounted for). From these data, it appears that contrast has its most important effects on the detection range and has least effect on accuracy of target identification.

# 4.0 MISSION SCENARIO

In order to relate this study to operational requirements, it is necessary to develop a standard mission scenario to serve as a context for the analysis of the variables affecting target acquisition. This section defines such a context with assumptions concerning the mission and the flight envelope in which an attack can successfully be carried out. The mission assumptions include: definitions of the mission type, attack decision rules, targets, time of day, and target location.

The operational factors and sensor system characteristics discussed in the preceding sections can be analyzed to define a set of boundary conditions on the operational flight envelope of the aircraft, especially with respect to range-to-target and aircraft altitude. The maximum range at which the operator can acquire the target is a function of target size, sensor capability, and a number of other variables which will be discussed later. The range of aircraft altitudes which will allow successful acquisition are bounded on the low side by terrain masking and on the high side by cloud cover. Altitude selection is further compounded by aircraft survival against a sophisticated antiaircraft defense. These factors will be integrated into mission envelope and a standard attack profile. Variables affecting target acquisition will be manipulated within the boundaries of this envelope to ensure that the study results will be applicable to the operational world.

## 4.1 BASIC MISSION ASSUMPTIONS

For the purpose of this study, we have assumed a European locale and an Eastern Block adversary. The adversary has attacked using massive armor and sophisticated mobile air defense. The overall mission is to stop the armor attack and set up a stable line of defense. Air missions are being flown round-the-clock against individual tanks and support vehicles to blunt the force of the enemy advance. Targets can show a full range of IR activity from hot (operating and firing) to cool (parked and inactive overnight). Missions are directed at activity in a precisely known geographical area saturated with targets. The target area has been designated a free-fire zone with the only constraints on weapons release being a fairly high certainty of target acquisition and kill. High air cover is provided ensuring an air-threat free environment for the attack phase of the mission.

## 4.2 DEFINITION OF AIRCRAFT OPERATIONAL FLIGHT ENVELOPE

The operational flight envelope for air-to-ground attack is a complex function that must balance aircraft survivability against probability of mission success. The ideal solution is one which does not degrade the probability of aircraft survival and still allows successful target acquisition. Researchers and engineers have tried to develop techniques for decreasing the vulnerability of attacking aircraft to the formidable defensive array presented by modern anti-aircraft weapons through systems analysis.

Standoff range was one important factor identified by this analysis as determining the survivability of an attacking aircraft. In the simplest case, air defense suppression, the effective range of the ZSU-23-4 is 2500 meters (Pretty, 1977). If the aircraft can accurately deliver ordnance from outside this range, one of the major low level air defense systems would be neutralized. Standoff range will also decrease the effectiveness of surface-to-air missiles against the attacking aircraft. The number of missile sites encountered on a mission can be expressed as a function of missile site density, missile range, and the distance the aircraft penetrates beyond the FEBA (Transue, 1971). This relationship is illustrated in Figure 27. If x, the distance traveled by the aircraft, is reduced by a significant standoff range, fewer sites will be encountered, and survivability will be enhanced. The limiting case occurs when the standoff range exceeds the range of the missile sites. The importance of standoff range as a means of reducing attrition and the relatively short acquisition ranges found with visual target acquisition (4000 to 6000 feet) reemphasize the need for sensor-aided target acquisition and standoff weapons.

Analysis of air-defense systems has also shown that tactics employing high speed, and low altitude attacks contribute to survivability (Maney, 1973; Tobin, 1976; Transue, 1971). The trend effects of speed and altitude on survivability are shown in Figure 28. Increasing the aircraft speed from the subsonic to the supersonic range appears to yield the greatest payoff. Low altitude attack is also an effective countermeasure. Tactics developed for the A-10 during exercises in Europe (Brown, 1977) indicate successful implementation of low altitude attack with approach altitudes as low as 100 feet and a pop-up maneuver to higher altitudes for weapons delivery. Such pop-up maneuvers are required for delivery of certain

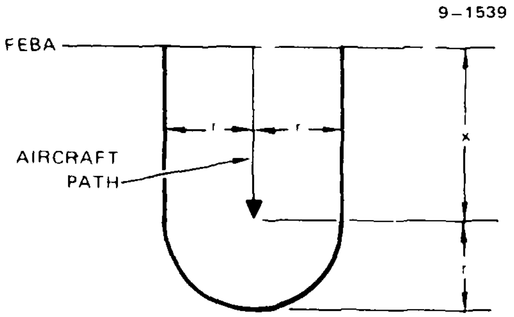



FIGURE 27 EXPECTED MISSILE SITES ENCOUNTERED BY PENETRATING AIRCRAFT (FROM TRANSUE, 1971)

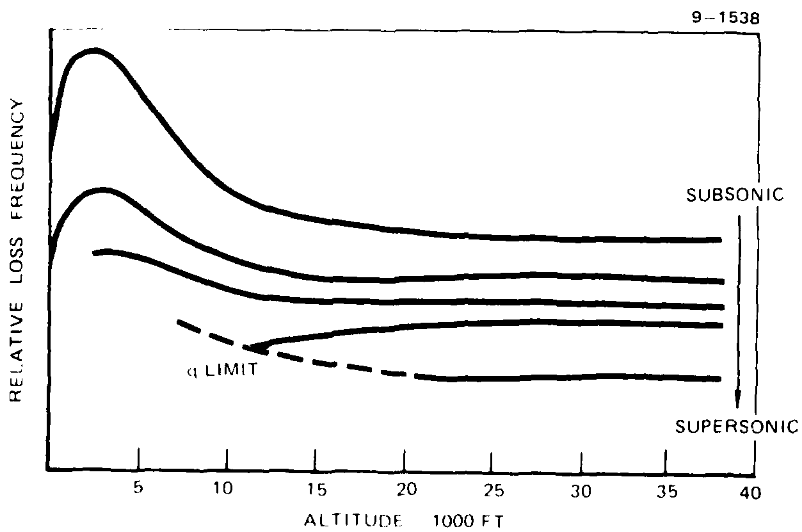



FIGURE 28 THE EFFECTS OF SPEED AND ALTITUDE ON SURVIVABILITY

types of ordnance and to achieve a line-of-sight to the target over intervening geographic obstacles.

The environmental constraints of weather and terrain masking present the most severe restrictions on the configuration of the flight envelope, setting boundary conditions which are specific to the geography and meteorological conditions occurring at any given time and place. The data on terrain masking indicate that an altitude of at least 3000 feet is required to obtain a clear line-of-sight to the target at ranges of 15,000 to 20,000 feet. Weather data (see Figure 13) indicate that this altitude will be below the ceiling 75 percent or more of the time (using the average for Germany) with a range of 50 percent to over 90 percent for the worst and best months respectively. The 3000 foot altitude appears to be a reasonable compromise between the terrain line-of-sight clearance requirement and the necessity of keeping below the cloud cover. The mission profile will therefore be configured as a low altitude penetration to the target area and a "pop up" maneuver to 3000 feet for the target acquisition phase. Since this altitude yields a maximum range to target of 20,000 feet for a number of real world cases (see Section 2), this value will be used as the end point in any parametric evaluation of the effects of range to target. A dive maneuver along the line-of-sight to the target will be initiated after the "pop up." This will bring the aircraft down to lower altitudes as the mission progresses. It will also reduce the time the aircraft would be vulnerable at the more dangerous, higher altitudes.

## 4.3 DISPLAY FACTORS

Given this mission envelope, the sensor/display system outlined in Section 3 must image the target with sufficient detail and size to allow acquisition by the observer. If the target image at the initial range (20,000 ft) is too poor for acquisition, the aircraft will be needlessly exposed to ground based antiaircraft defense. The target detail is a function of the display resolution and the target size. The geometric aspects of the system which define target size can be detailed using the information presented in Section 3. A sensor FOV of one degree square was specified for a standard FLIR system. The cockpit display consisted of a six inch square, standard 525 TV line CRT system (480 active image forming viewed at a design eye distance of 28 inches (AFSC DH1-3, 1972). Under these conditions the display would subtend an angle of 12 degrees at the eye.[6]

A one degree FOV system at a 3000 foot altitude and 20,000 foot slant range (the values selected in the above paragraphs) will have a depression angle of 8.5 degrees and image an area on the ground 2400 feet in length. A 25 foot target would take up 1/96 of this length. Using this proportion for the display, the target will subtend a visual angle of 7.5 minutes of arc (1/96 of 12 degrees) and have 5 TV lines across target for the maximum and two to three TV lines for the minimum target dimensions (assuming the normal length to width ratio for tracked vehicles). This value approximates Johnson's (1958) criteria for detection, i.e., the ability to say with certainty that an object is present. Thus, at the 20,000 foot range the target will be detectable but not recognizable. This range is an ideal starting point for the study as the target will appear below acquisition threshold and gradually increase in size until acquisition occurs. This will allow the observation of the perceptual process involved in target search and acquisition as a function of time and target size. For the purposes of defining an operational flight envelope, however, this would not be the ideal mission configuration as the aircraft would be exposed needlessly to enemy fire for the period of time it would take for the target to become recognizable. In an operational setting the maximum range, the point where the aircraft initiates the "pop-up" maneuver, should be set at a distance where the target can rapidly be acquired on the display. The results of the parametric study developed in the following sections should provide estimates of this maximum range to target.

---

[6] The visual angle can be calculated by the formula:

$$\tan VA = \frac{S}{d}$$

where:

VA = the visual angle
d = the viewing distance
S = the size of the object viewed.

## 5.0 INDEPENDENT VARIABLES

The target acquisition problem is complex because of the large number of interacting variables which can determine performance. This section separates these variables into general groupings and traces effects and interactions to determine their impact on the acquisition process. The chain of events which terminates at target acquisition begins with a real world scene being viewed by an airborne sensor under some set of environmental conditions. The characteristics of this sensor interact with those of a display to produce an image. The image is then viewed by an observer whose acquisition response will be tempered by what he sees, his training, and other psychological variables. This process is illustrated in Figure 29.

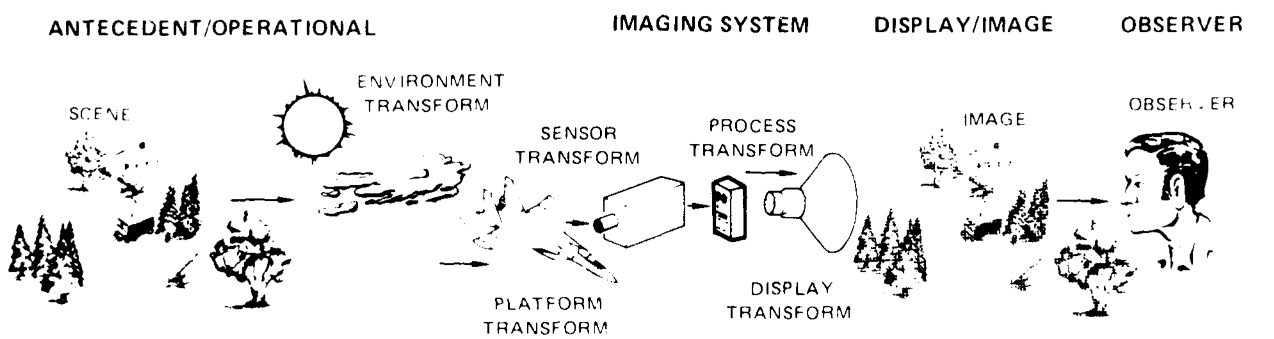



FIGURE 29 RELATIONSHIP BETWEEN VARIABLES

Based on this chain of events, four categories of variables can be defined: antecedent/operational, imaging system, display/image, and observer. The antecedent/operational variables can be grouped into those associated with the scene and target, environmental factors, and dynamic factors introduced by the aircraft. These variables (see Figure 30) are delineated by the operational scenario and define the input to the imaging system. The imaging system consists of the sensor and display (see Figure 31) and determines the characteristics and quality of the image seen by the observer. Display/image factors represent the output of the sensor system with respect to the scene identified by the antecedent/operational variables. This output is what the observer actually sees. All information processing and decision-making on the part of the observer are based on the information present in the display/image. The variables which define this information are listed in Figure 32. The final set of variables which will influence the acquisition process are those affecting the observer. These may be grouped into sensory capabilities, physical state, psychological factors, and environmental effects (see Figure 33).

9–1556

**SCENE/TARGET**

- TARGET
  - SIZE
  - INTERNAL COMPLEXITY
  - CONTOUR
  - EMISSIVITY
  - CAMOUFLAGE
- SCENE BACKGROUND
  - TERRAIN MASKING
  - COMPLEXITY STRUCTURE
- TARGET SCENE INTERACTIONS
  - TARGET LOCATION
  - CONTRAST
  - CONTEXT CUES
  - CLUTTER ELEMENTS

**ENVIRONMENT**

- TEMPERATURE HISTORY
  ATMOSPHERE
  - TRANSMITTANCE
  - SCATTERING
  - PATH TO TARGET

**PLATFORM**

- ALTITUDE
- RANGE TO TARGET
- DEPRESSION ANGLE
- VIBRATION
- SPEED

FIGURE 30 ANTECEDENT/OPERATIONAL VARIABLES

**SENSOR**

- OPTICS
  - DIAMETER
  - F NUMBER
  - FOCAL LENGTH
  - OPTICAL TRANSMISSION
- DETECTOR
  - INSTANTANEOUS FIELD OF VIEW
  - DETECTORS IN PARALLEL
  - DETECTORS IN SERIES
  - DETECTOR SIZE
  - PEAK D*
- SCANNER
  - FRAME RATE
  - SCAN EFFICIENCY
  - OVER SCAN RATIO
- SYSTEM
  - HORIZONTAL FOV
  - VERTICAL FOV

**DISPLAY**

- SIZE
- INTERLACE
- FRAME RATE
- GRAY SHADES
- TV LINES
- RESOLUTION
- BANDWIDTH
- PERSISTENCE

FIGURE 31 IMAGING SYSTEM VARIABLES

9 1557

- TARGET SIZE
  - HEIGHT
  - WIDTH
  - CROSS SECTION
  - PERIMETER
  - AREA
- GROUND RESOLUTION
- IMAGE SCALE
- ASPECT ANGLE
- TARGET DISPLAY SIZE RATIO
- DISTORTION
- RATE OF SCALE CHANGE
- TIME-ON-DISPLAY
- CONTRAST
- DYNAMIC RANGE (GRAY SHADES)
- TARGET SIGNATURE

FIGURE 32 IMAGE VARIABLES

- SENSORY
  - DARK ADAPTATION
  - CONTRAST DISCRIMINATION
  - VISUAL ACUITY
  - BRIGHTNESS THRESHOLD
  - FLICKER THRESHOLD
- PHYSICAL
  - STRESS
  - FATIGUE
  - NEURAL TRANSMISSION TIME
  - TASK DIFFICULTY
- ENVIRONMENT
  - VIBRATION
  - NOISE
  - HUMIDITY
  - "G" LOAD
  - AMBIENT ILLUMINATION
  - TEMPERATURE
- PSYCHOLOGICAL
  - MOTIVATION
  - DECISION CRITERIA
  - TRAINING
  - ATTENTION

FIGURE 33 OBSERVER VARIABLES

Analyzing all the variables listed is a difficult task because of the interactive effects among categories. Each category, however, represents a different stage in the acquisition process. The antecedent/operational category defines the physical properties of the stimulus; the sensor system processes these inputs, and the display/image presents the output to the observer. Thus, to have an effect on acquisition, the variables must be relatable to the output at the display/image-observer interface.

This section will review the variables listed in the antecedent/operational, the display/image, and the observer categories and provide a basis for the selection of variables for the Phase II study. The sensor/display variables will not be reviewed as they are primarily image processors and, for a given system, will have a constant effect. We have defined a representative state-of-the-art sensor and display system in Section 3 as part of the mission review. This system will be fixed during the Phase II study.

## 5.1 ANTECEDENT/OPERATIONAL VARIABLES

A sensor system presents a representation of the real world to the observer. The antecedent/operational variables are those aspects of the world which can affect target acquisition performance. The major groups of these variables relate to the following general areas: scene/target, environment, and platform. The scene/target variables describe the state of the real world, environmental variables modify the energy received by the sensor and set limits on factors such as range to target, and platform variables define the geometry and dynamics of the image on the display. These three groups of variables control what is imaged and the conditions under which it will be viewed by the sensor.

### 5.1.1 Scene/Target

Scene/target variables determine the content of the image. Foremost among these inputs are those provided by the target itself and the properties which make up the target signature, the properties of the scene, and scene-target interactions.

#### 5.1.1.1 Target

A target signature can be defined as those target attributes uniquely characteristic of the particular target. Like a written signature, differences may exist between successive images of the target, but its essential identity remains constant and recognizable. The human operator is able to discriminate the consistencies and identify the target under a wide range of conditions of shifting aspect angle, image scale, coloration, sun angle, and orientation. The mechanisms by which he is able to do this are largely unknown; although research efforts are currently being directed toward this problem.

The three most important characteristics of a target are its size, contour, and internal complexity or detail. Actual target size is a variable fixed by the goals of the mission and, as such, cannot be readily manipulated. The sensor system and display must, therefore, be designed and configured to image a target at a scale and resolution which permits acquisition by the observer. Thus a system designed for use against buildings, bridges, and airfields may be considerably different from one designed for use against trucks and tanks. The target size on the display will be a function of the sensor FOV, slant range to target, and the sensor depression angle. The target size on a display is approximated by the equation:

$$T_S = S_D \left( \frac{S_T}{(R_S) \tan FOV} \right)$$

where:

$T_S$ = Target size on display

$S_D$ = Display size

$R_S$ = Slant range

$S_T$ = Target size perpendicular to sensor line-of-sight

FOV = Field-of-View of sensor

The value of $S_T$ is calculated from the relationship:

$T_h\ (\cos\theta) + Tw\ (\sin\theta)$ where:

$T_h$ = Target height

Tw = Target width or length as appropriate

$\theta$ = The sensor depression angle

As the depression angle approaches 90 degrees, $\cos\theta$ approaches zero; and the length or width of the target is the determiner of the image size. At small depression angles, $\sin\theta$ approaches zero; and the target height becomes the major determinant of image size. (See Figure 34)

Target contour will change as a function of orientation of the target to the sensor. Despite these changes, observers seldom have difficulty in recognizing a target because of contour changes. One of the major purposes of camouflage is to break up the target's natural contour. Studies (Jarvis, 1974; Humphreys and Jarvis, 1974; Grossman, 1975) of camouflage have shown that patterned vehicles were more difficult to detect than solid color vehicles under a number of lighting conditions. The patterning serves to break up the expected contour of the vehicle, making it more difficult to detect.

A target's internal complexity or detail is the third factor contributing to a unique target signature. This internal detail is important only to the extent that it helps to distinguish the target from other targets or the background. The detail must be imaged on the display with adequate contrast and resolution to be perceived by the observer. As few as two TV lines will allow the observer to distinguish the presence or absence of a detail. This is often enough to make significant distinctions between targets, such as differentiating between the turret of a tank and the open cupola of an AAA vehicle when both are mounted on the same chassis. Internal detail is particularly important for interpreting FLIR imagery where significant differences can occur as a function of target temperature.

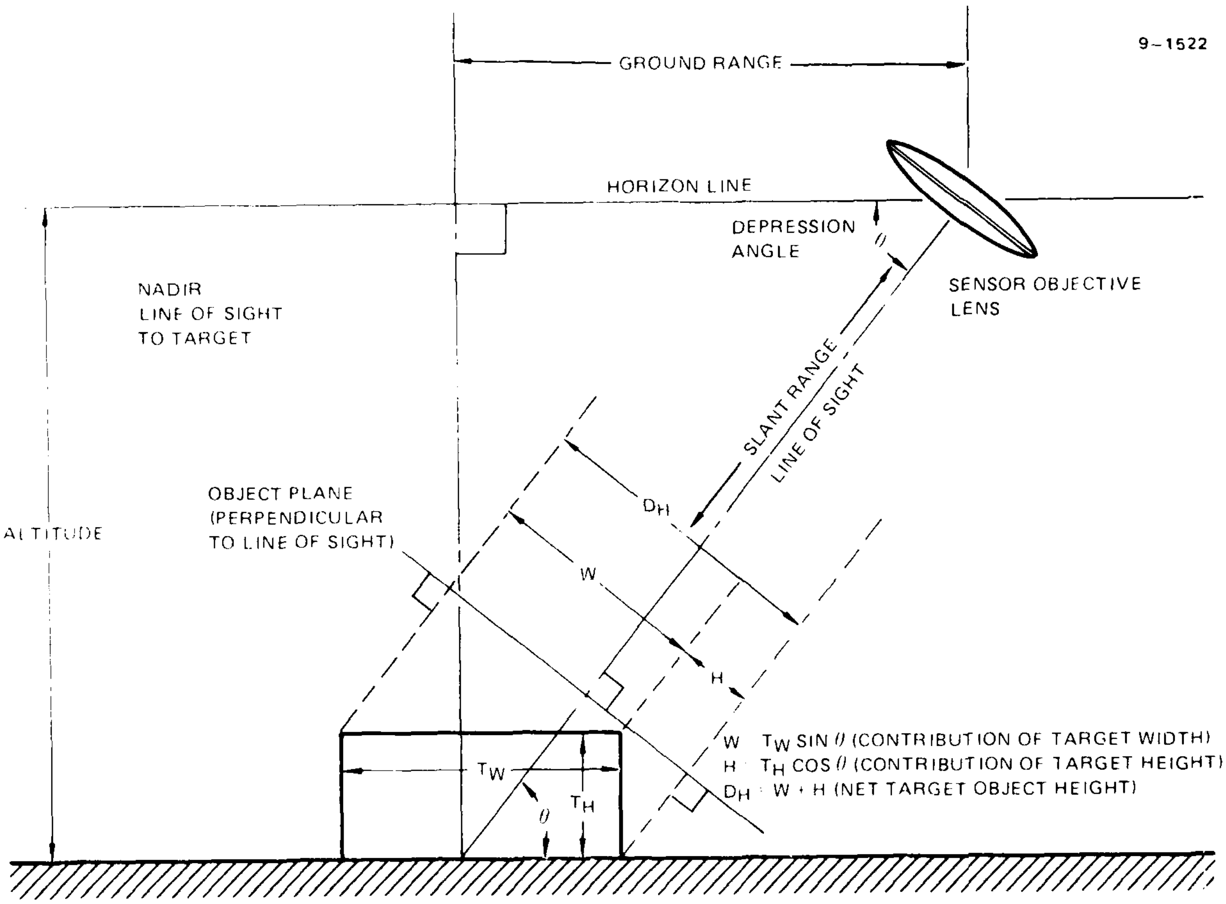



FIGURE 34 DETERMINATION OF TARGET IMAGE SIZE

Target and background materials are the source of IR wavelength energy and have a spectral and spatial signature. Typical FLIR systems use broad band detectors, e.g., 8-14 $\mu m$, so the spectral signatures are integrated to produce a net intensity sensitivity analogous to that of a monochrome television camera. The intensity distribution of the spatial signature is what we shall refer to as the target IR signature. These intensities have a range of values which is important in determining the display dynamic range requirements.

IR emissions from common materials occur because the materials have a temperature greater than absolute zero. A perfect radiator is a black body and radiates a spectral density $J_\lambda$ according to Planck's law which is:

$$J_\lambda = \frac{A\,2\,c^2 h}{\lambda^5\,(\epsilon^{hc/K T}-1)}$$

where: A is the area of the radiating surface, T is its absolute temperature, c is the velocity of light, h is Planck's constant, K is Boltzman's constant, and $\lambda$ is the radiation wavelength.

If the Planck law is integrated over all wavelengths, the Stefan-Boltzmann law is obtained. The simplest, and probably the most frequently used, modeling of real world targets is to assume they are gray bodies with an emissivity (efficiency of emission), $\epsilon$, and that the Stefan-Boltzmann law applies so that the radiated intensity is:

$$J_e = \frac{A\epsilon\,\sigma\,T^4}{\pi}$$

where, $\sigma$ is the Stefan-Boltzmann constant, $5.67 \times 10^{-12}$ w/cm$^2$ (°K)$^4$. Thus, the radiated intensity for a given target is a function of emissivity as well as temperature.

Emissivity is a characteristic of the material and the local surface condition, e.g., paint color and condition and surface texture. Thus, it generates spatial variations in intensity over the target and background that are analogous to, but distributed differently from, the variations in scene brightness that are observed at the visual radiation wavelengths. Typical emissivity values vary from less than one percent for polished metallic surfaces to 97 percent for some tree bark, twigs, and loam soils. Paints and anodized metals generally have values in the range of 70 to 95 percent.

The temperature, T, is a variable depending on many factors -- both intrinsic and environmental. Intrinsic heat sources include the obvious, such as warm blooded animals, running vehicle engines, hot muffler and exhaust systems, and hot gun barrels. Friction heat can also raise temperatures in items such as the drive and idler wheels on tanks and the tires on trucks. The primary environmental heat source is solar irradiance. Thermal effects of solar irradiance at all wavelengths contribute toward establishing the target/background signature. Due to variances of thermal conductivity and absorbtion, a pattern of temperature differences is established. These differences along with intrinsic heat sources contribute to the target signature.

Unlike the visible signature which is essentially instantaneous and the emissivity which is constant, the temperature is a function of the object's history. Time since application or removal of a heat source, thermal conduction of the material, the temperature of surrounding materials, convection effects of wind and rain, and the integrated effect of multiples of all these contribute to the temperature at any given time. Since many of these are time-varying, the local material temperature is also time-varying. When the local material temperatures vary spatially over the target and background, a target/ background signature is developed (neglecting emissivity effects).

The combined effects of temperature and emissivity variations at any instant in time form the spatial IR intensity contrasts of the target/background by the relation:

$$\frac{dJ_e}{J_e} = \frac{4dT}{T} + \frac{d\epsilon}{\epsilon}$$

Note that negative temperature or emissivity terms can offset the alternate contrast source so that the resultant intensity contrast is reduced to zero. This condition generally occurs in the real world twice a day and is called crossover. During this time the target/background contrast polarity reverses due to the addition or loss of solar irradiance in the diurnal cycle. Contrast will also tend toward zero for terrain features after extended periods of low, heavy overcast. Extended duration winds will also reduce target contrast.

Another source of radiant energy is reflected energy. The surrounding earth and cloud cover emit radiation in the 8 to 14 $\mu$m region which is reflected and makes a minor contribution to the target signature. The reflectance contribution from solar irradiance is not significant for sensors operating in the 8 to 14 μm region, but is significant for those operating in the 3 to 5 μm region. Since most FLIRs operate in the 8 to 14 μm band, the contribution of reflected energy to the target/background signature is minimal.

Often the combined effects of temperature and emissivity are called an equivalent temperature (ET). If it is assumed that the emissivity is equal to one, then the ET is the value needed to produce the same signal intensity. The difference in ETs for a "target" and its background is called the equivalent temperature difference (EΔT). Often the terms "target temperature" and "temperature difference" are inaccurately substituted for EΔT.

The dynamic range of typical scenes imposes a requirement of 20° to 40°C EΔT covering the "black" to "white" range of the FLIR display. While hot spot intensities might have an EΔT of 50°C or more, the signal corresponding to EΔT values greater than maximum can generally be truncated with little or no loss of required information. EΔTs within a target can vary as much or more than the EΔT between the target mean temperature and its mean background. The spatial variations of intensity are analogous to the visual signature for targets and background. Our signature simulation is based on duplicating these spatial signatures with sufficient dynamic range in the display image to approximate the EΔTs in the scene. Targets selected for simulation will have a variety of signatures varying along shape and contour dimensions, and overall target activity or brightness to ensure an adequate sample on which to base our evaluation of the effects of the other variables.

5.1.1.2 Scene Background

The scene/background in which the target is located can play an important role in target acquisition. Terrain contour and local features can mask or obscure the target from the aircraft line-of-sight. This frequently occurs during low altitude flight, especially at long ranges from target. The structure of the terrain can also degrade acquisition by presenting a perceptually complex background against which to perceive the target. These factors are typically absent from laboratory studies of target acquisiton but need to be considered if any meaningful generalizations are to be made from basic research to the operational world.

Masking - The first requirement for target acquisition is a clear line-of-sight to the target. Any object in the line-of-sight will mask or obscure the target, decreasing the probability of acquisiton. Targets can be obscured as a function of terrain roughness, foliage, and cultural features. Direct measurement of the probability of an unobscured line-of-sight has been attempted from the aspects of both the area visible to the attack aircraft (see Figure 35) and the direct line-of-sight from the target to the aircraft (see Bing and Stohler, 1974, for a review of these attempts). To date there has been little success in quantifying the variables which predict the probability of target masking.

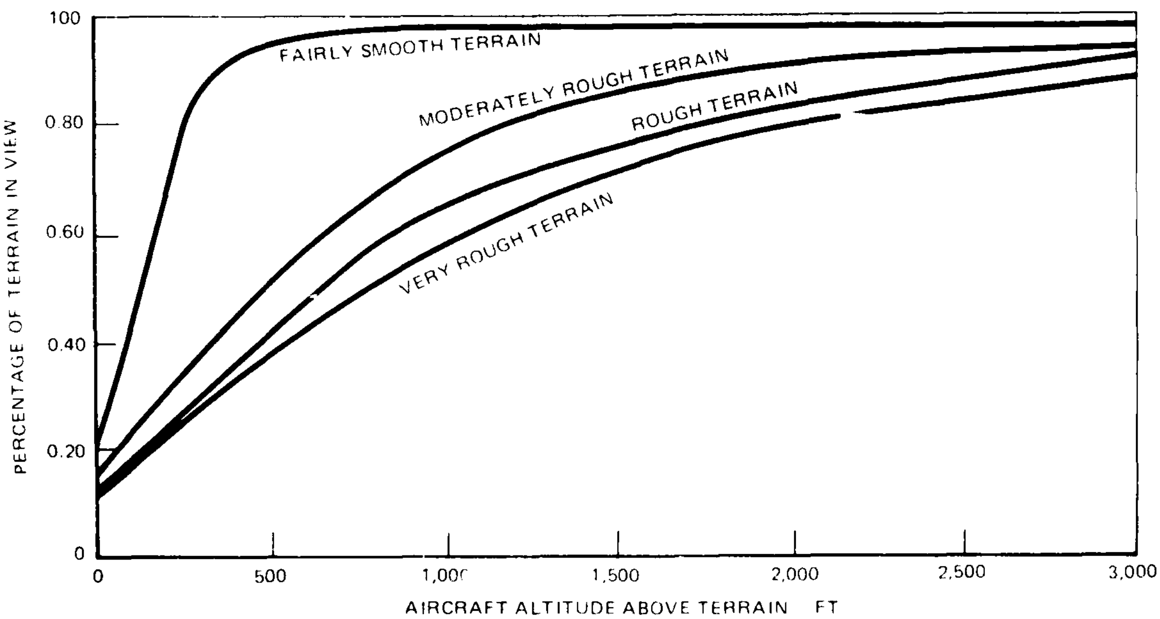



FIGURE 35 PROBABILITY OF CLEAR LINE-OF-SIGHT FROM AIRCRAFT (BASED ON 12,000 FOOT TERRAIN PROFILE) (FROM ERICKSON, 1961)

Probability is generally measured as the number of points that are in the line-of-sight of the aircraft compared to the number of points which are masked from view. Inherent in this measure are both the altitude of the aircraft and the ranges for which the probability is being calculated. These factors are treated in Section 2.3. Problems arise with the calculation of the probability of a clear line-of-sight as there are no clear criteria for establishing the number of points to be measured or means of accounting for foliage or cultural features.

The height, density, and cluster density of foliage and cultural features are factors which can contribute to target masking. It is generally recognized that the height and density of the foliage, which can change with the seasons, will effect target masking. Field studies (Ballistics Analysis Laboratory, 1959) have indicated that for a seven foot target, probability of target unmask from a low altitude aircraft (324 ft) decreased from 90 percent to 30 percent with the presence of foliage. This effect is even more severe at lower altitudes.

Complexity/Structure - The complexity, heterogeneity, or "busyness" of the target background and acquisition are inversely related. Generally, with an increase in complexity there is a decrease in target detectability. The relationship, however, is complex. Conklin (1962) emphasized the difficulty in measuring target-background distributions due to the essentially psychological nature of the problem. He listed seven background measurements related to variables that may add visual noise to the target acquisiton task. These measures are:

"A. The number of objects per search area.

B. The number of line segments per search area (in aerial photographs line segments may represent city streets).

C. The number of points of intersection of line segments.

D. The number of curvilinear objects minus the number of straight-sided objects divided by the total number of objects. (This can serve as a measure of slope heterogeneity; zero represents maximum slope heterogeneity.)

E. A measure of size variations within the complex of objects, i.e., range, average or standard deviation (an estimate of size heterogeneity).

F. A measure of brightness variations among the objects; range, average or standard deviations (an estimate of brightness complexity).

G. A measure of complexity variations among the objects in the field. (One or more of the shape complexity measures discussed previously can be employed to obtain a range, average, or standard deviation as an estimate of heterogeneity in this dimension.)"

It must be emphasized, however, that these measures have not been developed to a level where they can be operationally defined or universally applied.

The importance of the background scene is increased when small targets (vehicles) at an unknown location are to be detected. Nygard, Slocum, Thomas, Sheen, and Woodhall (1964) found, in a series of experiments, the probability of target detection varied not only with the type of background but also with the class of target embedded within the background. Assuming background as a unitary concept with a number of input factors, they developed a weighted (linear) combination model for defining target background:

$$C = K_1V_1(d_1) + K_2V_2(d_2) +++ K_NV_N(d_N)$$

K = weights

V = functions

d = dimensions

Although a linear weighted model has a face validity appeal, there are several difficult problems that must be considered. First, one must be able to specify the relevant perceptual dimensions that contribute to background complexity. Also, the weights and functions for each dimension must be empirically determined under a wide variety of situations. However, the most critical aspect of the model is the assumption that the dimensions are perceptually additive rather than interactive, an unlikely assumption from what is known about human perceptual functions. Rhodes (1964), in a factor analytical investigation of the predictability of target acquisition from aerial reconnaissance photography, found that human judgments of the difficulty of target recognition problems correlated with subject performance. He stated that, "Raters were able to make highly reliable and seemly valid judgements about complex perceptual characteristics of aerial photographs." The analysis indicated that a number of perceptual dimensions identified as predictive factors were interrelated.

Based on these findings, any study devised for measuring target acquisition must take cognizance of the background scene and the interactive processes in human perception. To accomplish this, a scene difficulty scale will be developed, and the interactions between scene background and target signature will be evaluated as part of our Phase II study of the target acquisition process.

5.1.1.3 Scene Target Interactions

Interactions between the target and the scene can also affect acquisition performance. These interactions result from both physical and perceptual factors. The effects of target location in the scene (independent of scene content) and the target/background contrast are physical interactions. The perceptual confusion caused by clutter and context cues to target location is a function of the scene content and, to an extent, the observer's perceptual set.

Clutter - Clutter has been defined as the number of objects in a complex visual scene. Experiments have shown that as clutter increases, target acquisition performance decreases (Boynton and Bush, 1957; Williams and Borrow, 1963). All of these studies, however, used clutter objects highly similar to the target objects. A field study (Whittenburg, Schreuler, Robinson, and Nordlie, 1959) compared acquisition performance for targets in open ground against that of targets next to natural terrain objects and found no differences. Bergert and Fowler (1970), using a terrain board simulation, found that nontarget-like background clutter consisting of rocks and trees had no effect on acquisition performance. Hilgendorf and Milenski (1974) obtained similar results using trees as the clutter objects for vehicle type targets.

The effects of clutter appear to be dependent on the degree to which the clutter object resembles the targets (Scanlan, 1977). Scrub vegetation will present a high degree of clutter with respect to a tank target and have very little effect on the acquisition of a bridge or aircraft revetment.

A major problem in studying the effects of clutter is the quantification of the degree of similarity to targets present in the clutter objects. Some success has been achieved using subjective estimates of relevant clutter (Rhodes, 1964), but no generally accepted objective techniques for clutter measurement are currently available.

Context Cues - Context cues are scene and target specific. They concern relationships between the scene content and the target which tend to cue the observer to the target location. Boats on or near a river or aircraft revetments in proximity to an airstrip are good examples of this relationship. The observer tends to search the scene for areas which have a high probability of containing a target. This phenomenon was demonstrated by Erickson (1964) where observers searching a cluttered display took significantly less time to search using a linear cue consisting of a road-like line down the center of the display. The context cue in most displays serves to direct attention to a small area and, in effect, reduces the size of the scene being searched resulting in reductions in target acquisition time.

The physical interactions depend on the characteristics of the target and the display, their relation to each other, and the effect this relationship has on the perceptual processes of the observer. These interaction effects contain aspects of both the sensory and information processing capabilities of the observer and, therefore, are subject to modification through training and/or practice.

Target Location - The location of the target in the scene with respect to the sensor line-of-sight will determine the location of the target in the displayed image. This factor has been demonstrated to have significant effects on target acquisition. Studies have shown (Enoch, 1959; Snyder, 1973) observers tend to concentrate their search in the central portion of the display. This strategy will have severe consequences on target acquisition using a stabilized image display, as targets in the periphery will migrate off the display as the sensor closes with the target area. Studies of this effect (Levine and Youngling, 1973) have shown significant deterioration in performance when the target initially appeared outside of the central two thirds of the display. A more appropriate search strategy would be to attend to the periphery first to acquire targets before they can migrate off the display. Proper training would assure that observers adopted this strategy for searching image-stabilized display systems.

Target Background Contrast - Target background cortrast refers to the displayed relationship between the brightness of the target to the brightness of the background. It is usually expressed as some ratio of these values. There are three frequently used contrast measures:

$$\text{Contrast Ratio (CR)} = \frac{B_{max}}{B_{min}} ;$$

$$\text{Differential Contrast (CD)} = \frac{B_{max} - B_{min}}{B_{min}} ;$$

$$\text{Modulation (M)} = \frac{B_{max} - B_{min}}{B_{max} + B_{min}} ;$$

where $B_{max}$ = the bright area luminance and $B_{min}$ = the dark area luminance. These values can be readily converted from one to the other by use of Figure 36.

For a FLIR system, the contrast on the display will be a function of the target and background temperature and emissivity, atmospheric attenuation of the emitted energy, sensor sensitivity, and display capability.

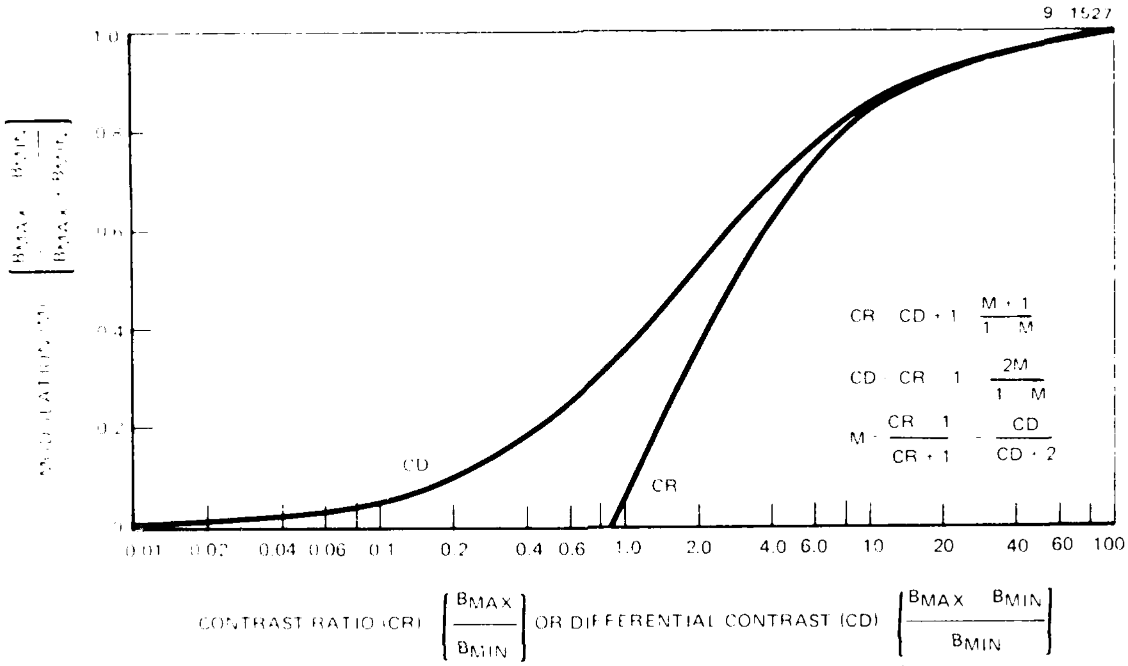



FIGURE 36 CONTRAST CONVERSION FUNCTIONS

Contrast has been studied extensively as a perceptual variable in both laboratory and applied settings. Blackwell (1964) conducted a series of studies in which he obtained over one million observations in an attempt to define the relationship between contrast and target size for differing levels of light adaptation and background brightness. These studies have shown that under proper conditions contrast differences as small as .001 can be detected. Under normal daylight viewing (100 foot Lamberts), a one minute of arc target at 25 percent differential contrast was detected 90 percent of the time. While many studies have investigated contrast as a perceptual variable (Taylor, 1961; Bos, Lazet and Bauman, 1956), the emphasis has been on the sensory aspects of the problem and not on target acquisition as it would apply to the real world. The studies have dealt with determining contrast detection thresholds for spots and resolution targets. Boynton, Ellworth, and Palmer (1958) investigated the effects of contrast on the detection of a solid shape target from among other similar shapes; but their targets did not have any internal detail, and contrast was held constant for all shapes. There have been relatively few studies investigating the effects of contrast on target acquisiton of real or simulated tactical targets. Thackham, Wade, and Clay (1966), in a field trial, found that static, high contrast targets yielded longer acquisition range than low contrast targets, but did not report any contrast measurements. Simulation studies (Ozkaptan, Ohmart, Begert, and McGee, 1968; Jones and Bergert, 1970; Bergert and Fowler, 1970) found significant improvements in detection and recognition performance as contrast increased from 5 to 50 percent with the major improvement occurring from 5 to 25 percent. Bruns, Bittner, and Stevenson (1972) found similar effects, although these data indicated improvements in performance over a range of 10 percent to 70 percent contrast. For the three performance measures used, contrast played an important role in target detection, accounting for 23.4 percent of the variation in performance, and lesser roles in target identification and probability of correct identification (12.5 percent and 2.7 percent of the variance respectively). Krebs and Graf (1973), in a study of simulated FLIR imagery, found similar results.

The effects of contrast on target recognition or identification present a different problem from that found in target detection. Increased contrast makes a target stand out from the background and reduces the difficulty of the observer's search task. Once the target is detected, however, the degree to which the overall background contrast will contribute to target identification is unknown. Studies of this nature present two significant problems: the sequential dependence of recognition/identification on detection, and the determination of the contrast value. The probability of detection sets an upper limit on the probability of recognition/ identification, as a target must first be detected before any further action can be initiated. Studies investigating the effects of contrast on recognition/identification (Bruns, Bittner, and Stevenson, 1972; Krebs and Lorence, 1974) have confounded detection performance with the measures of recognition/ identification. While they both found contrast effects, it is unclear whether these effects were independent or a function of the level of target detection.

Real world targets are complex and usually have considerable detail internal to the overall target shape. The relative contrast of this detail is typically averaged to yield an overall "average" target brightness. This can obscure the effects of target highlights and artificially decrease the effective contrast of the target. This is especially true of FLIR targets where hot engines or exhausts provide local high brightness or highlight returns on the image. Krebs and Lorence (1974) investigated highlights and average contrast measurement techniques for FLIR target acquisition. The values varied from no difference to differences as great as 32 percent contrast (48 percent average vs 80 percent highlight). Their data also indicated that maximum contrast was the most important contributor to variations in performance for both time and accuracy measures. Based on these findings, future studies investigating contrast as a variable in target acquisition should evaluate expected target signatures to determine whether significant differences exist between average and highlight contrast and which of these measures is most appropriate to the study. Both types of measures will be obtained in the Phase II study and evaluated as part of the data analysis to determine which of the two has the greatest effect on acquisition.

### 5.1.2 Environmental Factors

The environment in which a FLIR sensor is used will have a significant impact on the system effectiveness. Environment refers to the conditions under which the sensor images a scene. Among the most significant conditions are the ambient temperature history of the scene and the characteristics of the atmosphere through which the scene is imaged. Temperature factors will determine brightness of the scene and target signature. Atmospheric characteristics will determine the amplitude and contrast of the signal imaged by the sensor.

The ambient temperature and temperature history will establish the background brightness of the scene in which the target appears, as well as the brightness at which the target is imaged. A typical scene will go through a diurnal cycle, heating up during the day and cooling off during the night. Targets, especially vehicles of all types, usually have a higher emissivity than natural terrain features. Since effective temperature is a function of emissivity and physical temperature, targets will appear brighter than the background during warming periods because they will emit or radiate heat faster than the surrounding area. During cooling periods, the targets will cool faster than the surround and appear darker than the background. At certain intervals, usually at dawn and dusk, a crossover occurs where the target and surround have the same effective temperature and, therefore, the same brightness. FLIR sensors will lose most of their effectiveness during these periods unless the target is thermally active. Target activity, such as running the engine, will warm up areas of the target and generate FLIR target signatures.

Small differences between target and background effective temperature are theoretically discriminable, since the thermal resolution of most modern FLIRs is less than 1/2 degree Celsius (C). A problem arises, however, from the fact that the temperature difference must be received at the sensor, and the intervening atmospheric medium tends to attenuate the infrared energy.

The atmosphere is transparent to only a limited portion of the infrared spectrum (1 to 20 micrometers). In addition, a number of atmospheric gases, such as $H_2O$, $CO_2$, $O_3$, $N_4$, CO, $CH_4$, and $HNO_3$ absorb infrared energy (see Figure 37). These gases are minor constituents of the atmosphere and, with the exception of water vapor ($H_2O$) and ozone ($O_3$), have relatively consistent distribution below 30,000 feet (Randall, 1975).

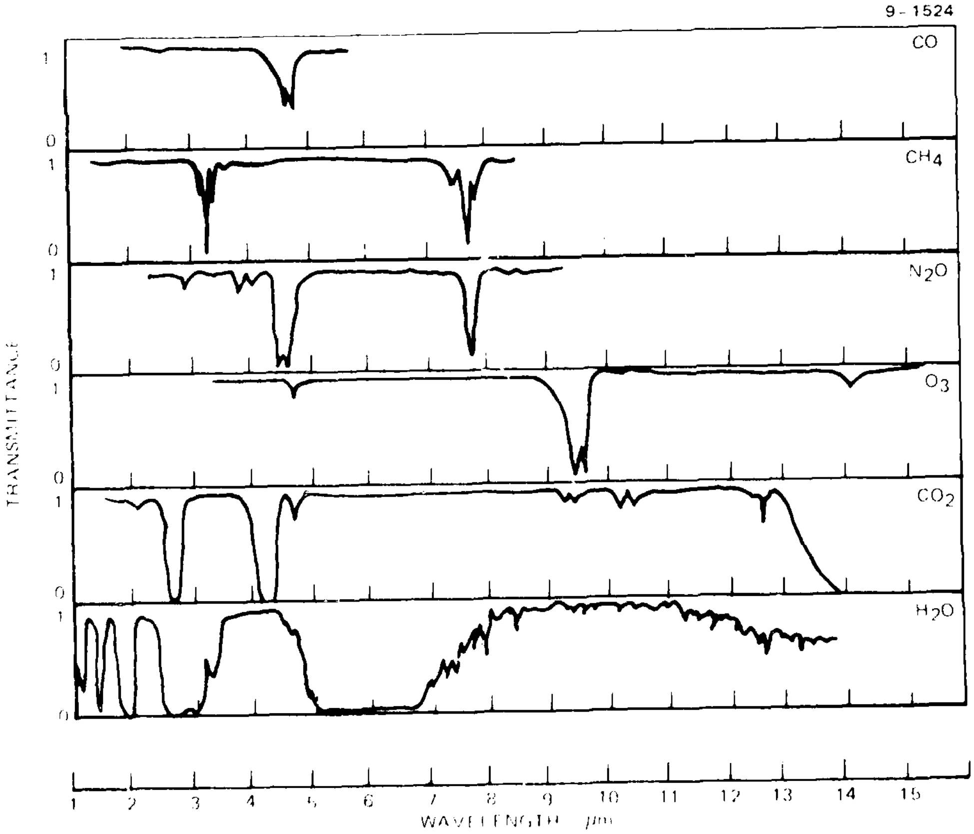



FIGURE 37 NEAR AND MID INFRARED TRANSMITTANCE SPECTRA OF A NUMBER OF GASES OCCURRING NATURALLY IN THE ATMOSPHERE (FROM RANDALL, 1975)

The amount of water vapor in the atmosphere between the target and the sensor must be considered when calculating the strength of the FLIR signal. Water vapor content will vary as a function of local meteorological conditions, but, given temperature and humidity, the overall amount along a given slant path can be estimated. The absolute amount of water in the air is the significant factor and not the humidity. Thus, temperature becomes as important as the relative humidity and is frequently the driving parameter. A hot desert with only 10 percent relative humidity has more water vapor along a given viewing path than a cold European winter day at 80 percent relative humidity (see Figure 38) (McClatchey, Fenn, Selby, and Garing, 1970).

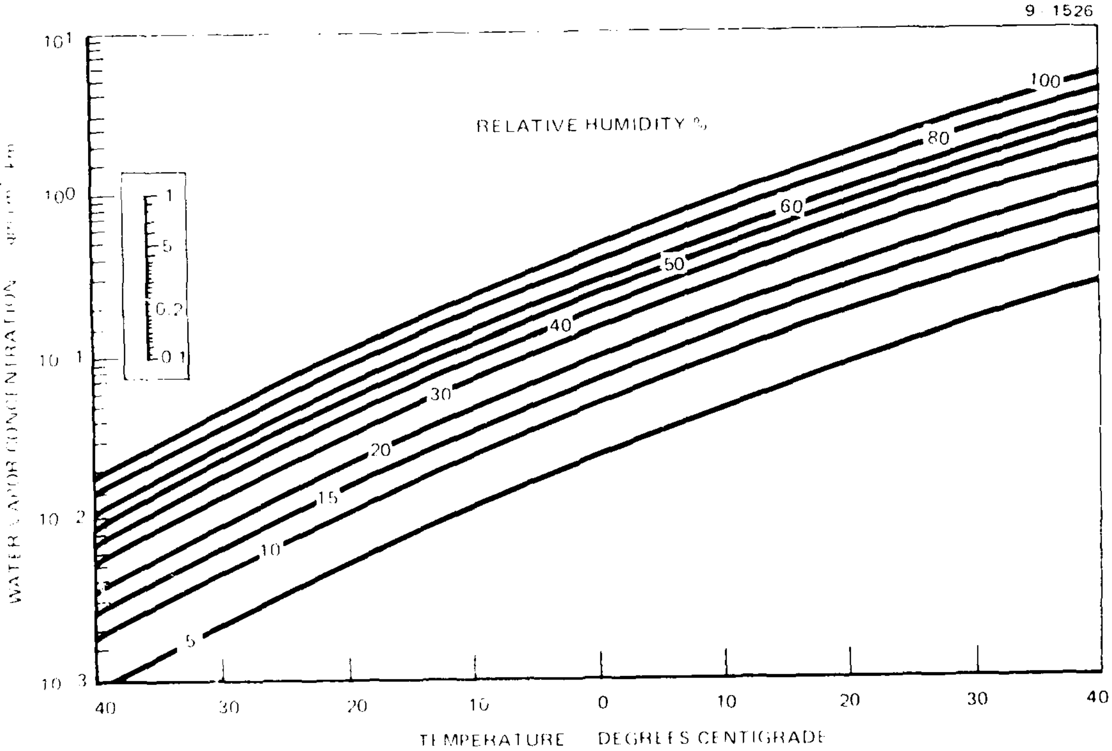



FIGURE 38 WATER VAPOR CONCENTRATION AS A FUNCTION OF TEMPERATURE AND RELATIVE HUMIDITY (FROM McCLATCHEY ET AL., 1970)

Aerosols or particulate matter suspended in the atmosphere also have significant effects on the FLIR image. In addition to attenuating the signal, the scattering caused by these particles mixes the energy radiated from various parts of the scene and ambient energy sources. The effect is a reduction of image contrast.

Where attenuation reduces the equivalent temperature below the sensor threshold, details will be lost; and the image will be seriously degraded. Biberman and du Mais (1976) have indicated that if a ratio of 2 or better between the mean resolvable temperature, and the target and background equivalent temperatures at the sensor, can be maintained, detection performance should not be degraded. For a state-of-the-art system, this would require a one degree equivalent temperature difference at the sensor.

In order to evaluate the effects of the atmospheric attenuation on performance, it is necessary to determine the degree of attenuation. Attenuation is a function of temperature, humidity, and aerosol content of the atmosphere and the path length and altitude from the sensor to the target. Because the calculations for attenuation are complex and the combinations of variables are very large, models have been developed to predict attenuation as a function of range for any combination of atmospheric conditions. One of the most advanced models is the Lowtran 3 model developed by the Air Force Geophysics Laboratory (Selby and McClatchey, 1975). This model provides a means for determining the sensitivity of the atmospheric transmittance to variations in each of the meteorological parameters. A series of atmospheric profiles were generated using Lowtran 3B, an advanced Lowtran 3 model having improved estimates of attenuation due to water vapor, and a better aerosol submodel, to evaluate the effects of attenuation on our proposed mission envelope. The results are shown in Figure 39. The data represent attenuation for standard weather conditions for a mid-latitude winter and maritime and rural aerosols. Starting altitude was assumed to be 4000 feet, and a slant range path was used as the sensor approached the target. At 20,000 feet, the proposed starting range, the worst case maritime aerosol condition showed 23 percent transmittance as compared with 38 percent for the rural aerosol. Using these attenuation values, equivalent temperature differences of three degrees for the maritime and two degrees for the rural aerosols are required to maintain a ratio of two or better between temperature differences and mean resolvable temperature at the sensor.

An analysis of FLIR target acquisition capability using actual weather data was performed by Biberman (1977). Daily weather summaries from Hanover, Germany, obtained for 1970 were used to model FLIR target acquisition for a tank target. The model indicated that a detection range of greater than 20,000 feet would be present at least 50 percent of the time throughout the year. Recognition ranges for the same data fell between 13,000 and 15,000 feet. While the system outlined in Section 3 differs considerably from that used by Biberman, the data indicate that acquisition would be possible over the ranges suggested for this study.

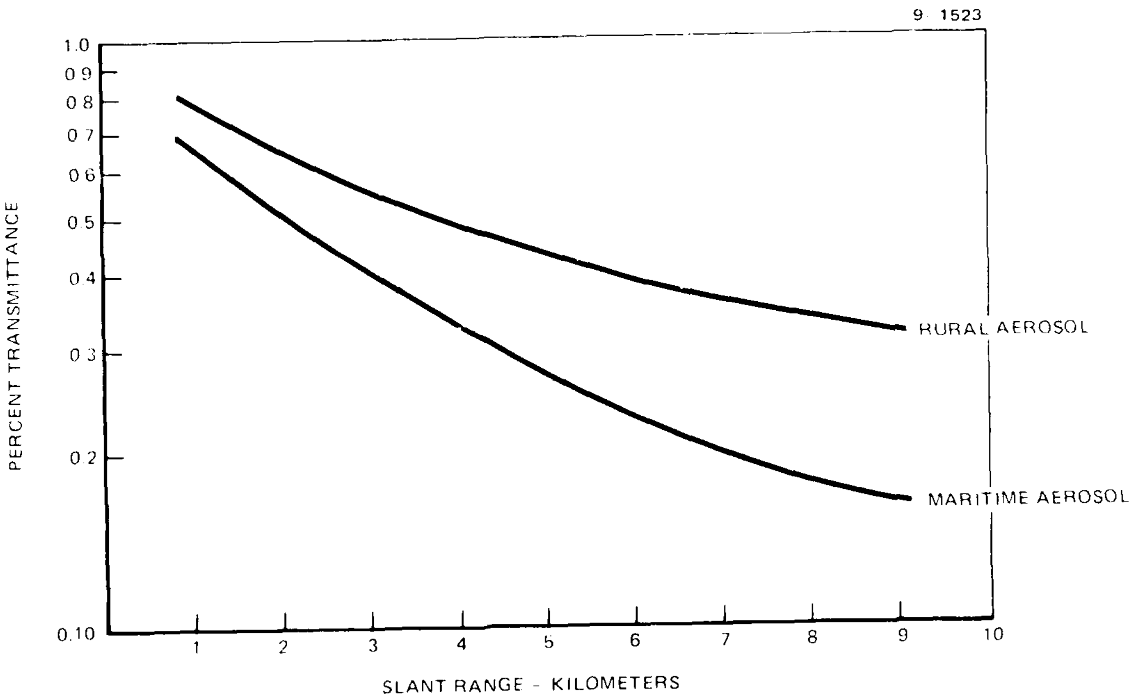



FIGURE 39 ATMOSPHERIC TRANSMITTANCE MID LATITUDE WINTER (TEMP –1.16°C, HUMIDITY 75%, VISIBILITY 3.048 KM)

Additional analysis of target acquisition through the atmosphere (see Section 3.1) was performed to evaluate the parameters of the proposed FLIR system. The probability of acquisition curves generated by the NVL model for our sensor indicated 75 and 60 percent probability of acquisition for the one and three degree $\Delta T$ cases at the extreme range to target, with a rapid rise in probability as range decreased. By 10,000 feet, both temperature differential cases showed over 97 percent predicted performance (see Figure 17). These data indicate that, for the selected mission scenario and ranges to target, atmospheric attenuation will not be a dominant factor in target acquisition. The data provided by this study will serve as a baseline against which to evaluate other atmospheric conditions and ranges to target where attenuation may present a problem. These studies will be considered during Phase III of this FLIR evaluation program.

### 5.1.3 Platform

The platform variables relate to the position and dynamics of the aircraft in space with respect to both the sensor and the target area. These variables will determine the scene geometry on the display and the dynamics of changes in scale and image motion. The altitude and depression angle of the sensor determine the sensor footprint and the slant range. The speed will determine the rate of change of the image, rate of zoom in the case of a stabilized image display, and rate of image motion down the screen for a moving window display. Vibration, another platform variable, will degrade visual acuity, especially at 10-25 Hz, but has little direct effect on the higher order processes such as target identification (Grether, 1971).

Altitude - The effects of altitude on target acquisition are confounded by a number of factors. For a given system of optics, increases in altitude will enlarge the area imaged by the sensor increasing the chance that the target is a significant cue to target location in the FOV. However, as the area imaged increases, the scale will decrease making it more difficult to acquire the target. A decrease in scale will also reduce the rate of apparent motion on the display.

Increased altitude will also change the apparent size and shape of the target. As altitude increases, the depression angle to the target (for a given range) increases. This results in a shift in the relative influence target height and length have on imaged target size. This relationship is discussed in Section 5.1, Target Size, and can be expressed by the equation:

Image size = Th (cos $\theta$) + Tw (sin $\theta$) where:

Th = Target height

Tw = Target width or length as appropriate

$\theta$ = Depression angle

The relative contributions of the target height and length as a function of depression angle are shown in Figure 40, a plot of the sine and cosine trigonometric functions. As can be seen from the figure, the maximum image size for a square target occurs at a 45 degree depression angle. For a 2:1 length to height ratio

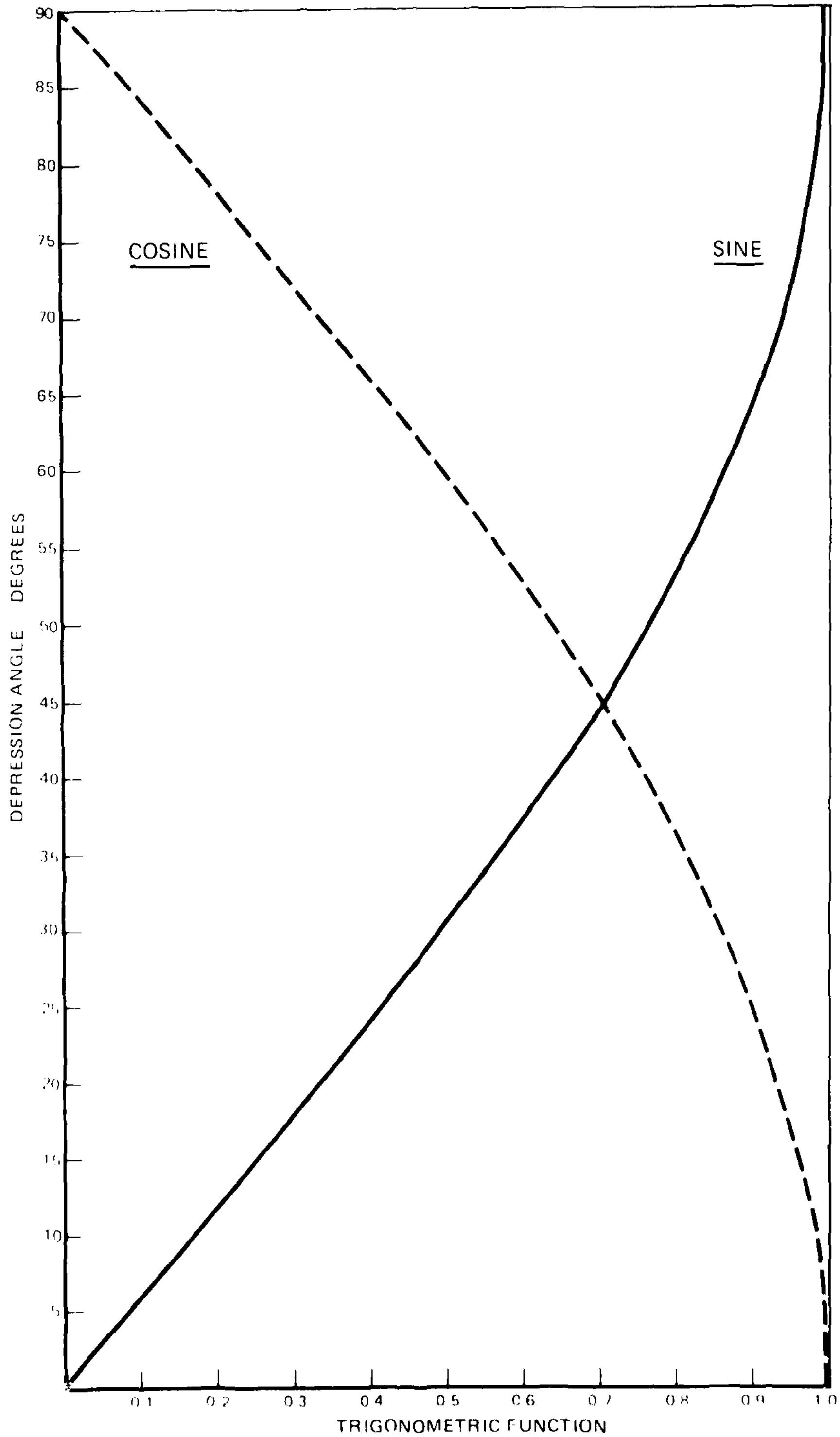



FIGURE 40 RELATIONSHIP BETWEEN TRIGONOMETRIC FUNCTIONS FOR SINE AND COSINE

target, the approximation for most vehicles, the maximum size occurs at a 65 degree depression angle.

For a level flight path, the aspect angle to the target will change as the aircraft approaches the target. The angle changes as a sine function, with 1/2 of the change (45 degrees) occurring when the slant range to target is equal to or greater than 1.4 times the altitude. It has been demonstrated (Wallace, Levine, Logan, and Struharik, 1968) that the introduction of five to seven degrees of aspect to a vertical image improved performance. Changes in aspect beyond seven degrees, at an 83 degree depression angle, yielded no additional improvement.

Speed - Aircraft speed will determine the dynamics of the image. For moving window displays, image motion down the display is directly proportional to speed with the exact rate determined by the image scale. Image motion rate in conjunction with display size will determine the time the target is available on the display. In addition, high rates of motion can affect acquisition performance by degrading visual acuity. Miller and Ludvigh (1962) reviewed the effects of image motion on visual acuity and found little effect below five to ten degrees per second for two minutes of arc targets. A study of dynamic acuity on TV display systems (Levine and Jauer, 1973) found significant degradation for targets smaller than two minutes of arc at motion rates as low as 2.8 degrees per second.

A six inch display, at the standard 28 inch viewing distance, subtends 12 degrees of arc. Practical considerations of target search will, therefore, generally require image motion rates below 2.8 degrees per second to allow adequate target acquisiton time. As noted in Section 3.2, FLIR System Geometry, three seconds appears to be a minimum for undegraded acquisition. For simpler tasks, the effects of image motion up to 10 degrees per second are a function of time-on-display. Erickson (1964) found no performance differences between static and dynamic target acquisition when time-on-display was equated for the two search conditions. Studies of the effects of speed on stabilized image displays indicate that percent correct acquisition and acquisition time go down as speed increases (Levine and Youngling, 1973). This study confounded rate of scale change with time-on-display, so the exact perceptual variables responsible for the drop in performance was unclear. Plans for the Phase II study have been configured to evaluate the relationship among speed, time-on-display, and rate of zoom as they affect target acquisition performance.

## 5.2 IMAGING SYSTEM DEFINITION

The imaging system is made up of the sensor and the display. The electronic variables associated with these two devices are highly interactive, and changes in one or two elements can result in the reconfiguration of the entire system. An indication of this interactive complexity is shown in Figure 41 where scene and image variables are listed along with the other variables which can affect the transfer of an image of the scene to the display. The combinations of electronic variables leading to the same or equivalent image outputs are indeterminant. In addition, while the electronic variables can be manipulated, the observer is relatively invariant. These sensor system characteristics allow us to treat the electronic variables relating to the sensor and the display as a set of black box variables. To this end, a set of representative, state-of-the-art sensor characteristics and a typical display (Section 3) have been defined as a baseline system for defining image quality. No attempt will be made in this phase to define further the electronic variables specific to these systems.

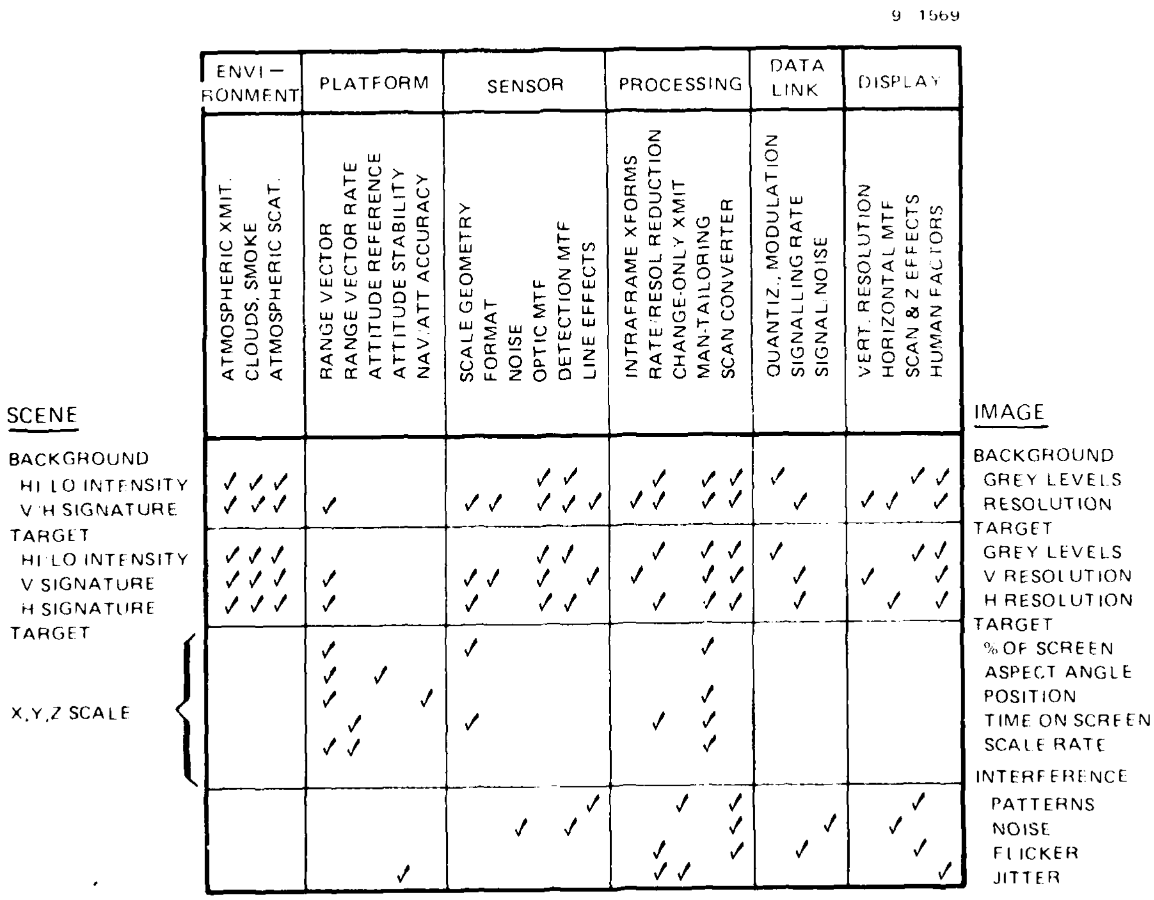



FIGURE 41 SCENE TO IMAGE INTERACTIONS

## 5.3 DISPLAY IMAGE VARIABLES

The interaction between operational/antecedent and sensor/ display variables determines the image on the CRT display. Variables which define the image quality and content provide information upon which the observer bases his acquisition response. Quality variables typically relate to contrast and resolution of the image. Content variables will relate to the target, image scale, rate of scale change, time-on-display, and ground resolution. The variables considered will completely define the image although they represent a partial listing of those which have been proposed by various authors (Snyder, 1973; Jones, Freitag, and Collyer, 1974).

### 5.3.1 Display Quality

A number of measures has been proposed to quantify display quality in a way which relates to target acquisition performance. Two of the most popular current measures are the display/signal-to-noise ratio (SNRD) developed by Rosell and Wilson (1973) and the modulation transfer function area (MTFA) developed by Charmin and Olin (1965) and applied to TV type displays by Snyder (1973).

SNRD - SNRD is a measure of the image quality required to recognize a target of a specific size. It is based on the measured video signal-to-noise (S/N) ratio of the video signal as it is inputted to the display. This value is modified to include the effects of video bandwidth, target and display size, and visual integration time. It is then combined with Johnson's concept of resolution over target (Johnson, 1958) to yield SNRD thresholds for equivalent bar patterns having the same aspect ratios as the targets in question. Thus, if Johnson's criteria required six lines-over-target for recognition, the SNRD required to discriminate a line frequency equal to the six lines per target minimum dimension on a given display would be the quality required for recognition. This concept is based on an evaluation of the electronics of the sensor display system as they interact with the perceptual capabilities of the observer (see Figure 42). It requires measurement or theoretical evaluation of the input signal to determine the video S/N ratio and makes a number of assumptions concerning the visual capabilities of the observer. The SNRD also assumes a step function probability with respect to acquisition at a given number of lines-per-target when referring to Johnson's criterion.

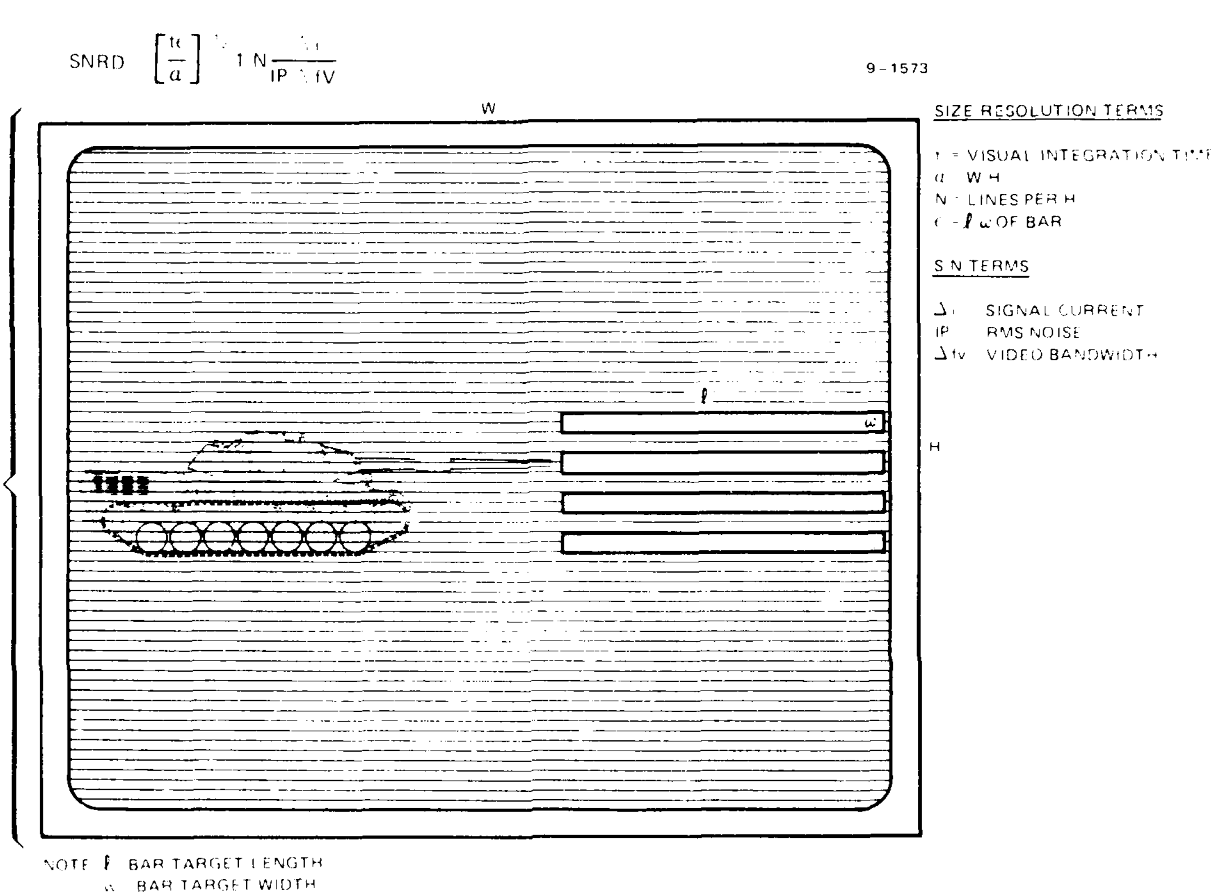



FIGURE 42 SNRD FOR AN IDEAL SENSOR

Johnson and Lawson (1975), in proposing their own technique to predict performance of an electro-optical system, point out that this step function will only approximate empirical data when the probability of acquisition as a function of lines-over-target is very steep. If the probability of acquisition as a function of lines-over-target increases slowly, the SNRD predictions become less accurate. Johnson (1958) originally observed that resolution requirements for target height in millimeters, as imaged on the screen, and the number of line elements per millimeter that can be resolved by the observer viewing the display under the same conditions as would occur during acquisition appeared to be a constant. This was the origin of the Johnson line criteria for acquisition.

What most people who have used the criteria fail to take into account is the requirement that the viewing and display conditions be the same as those which would be used for target acquisition. Taking this into account, the S/N ratio is subsumed in the resolvable lines measure. This was shown in a study by Levine, Jauer, and Kozlowski (1970) which varied both lines-over-target and S/N ratio and found that resolvable lines over target obtained using Johnson's methodology accounted for virtually all of the variance in performance attributable to S/N ratio. Additionally, Johnson (1958) and Levine et al. (1970) independently found that the probability of acquisition will vary as a function of resolvable lines for both target type and the kind of response required: detection, recognition, or identification. This finding became the basis of the Johnson and Lawson (1975) formulation for predicting target acquisition performance, a model which bases prediction on a theoretical or empirical determination of resolvable lines on the display and then calculates performance as a function of the number of lines across the target's minimum dimension (see Figure 43). Despite their differences in approach, both Rosell and Johnson use the same conceptual basis, i.e., performance is a function of the resolvable detail in the target. The SNRD defines this value with respect to display and electronic variables while Johnson's formulation is expressed in perceptual terms. With a modest amount of manipulation and modification, either formulation can be converted into the other; although judging from the data presented in Johnson and Lawson (1975), their technique currently achieves better prediction for complex targets.

MTFA - The MTFA approach to estimating image quality is based on estimates of the overall image quality independent of target size. It is derived from the modulation transfer function (MTF) of the display and the contrast demand function of the human observer. The MTF is a plot of the contrast modulation transfer ability of the display with respect to sinusoidal intensity patterns at parametrically varied spatial frequencies. Engineers and designers have found it very useful because the MTFs of each element in a display system can be combined mathematically to obtain the MTF of the final display without physically putting the system together. The contrast demand function (CDF) is a measure of the modulation contrast the observer requires to discriminate between spatial frequency pattern elements. In general, as modulation contrast increases, the observer can perceive progressively higher spatial frequencies; however, the same increase in modulation tends to decrease the display's capability to image higher spatial

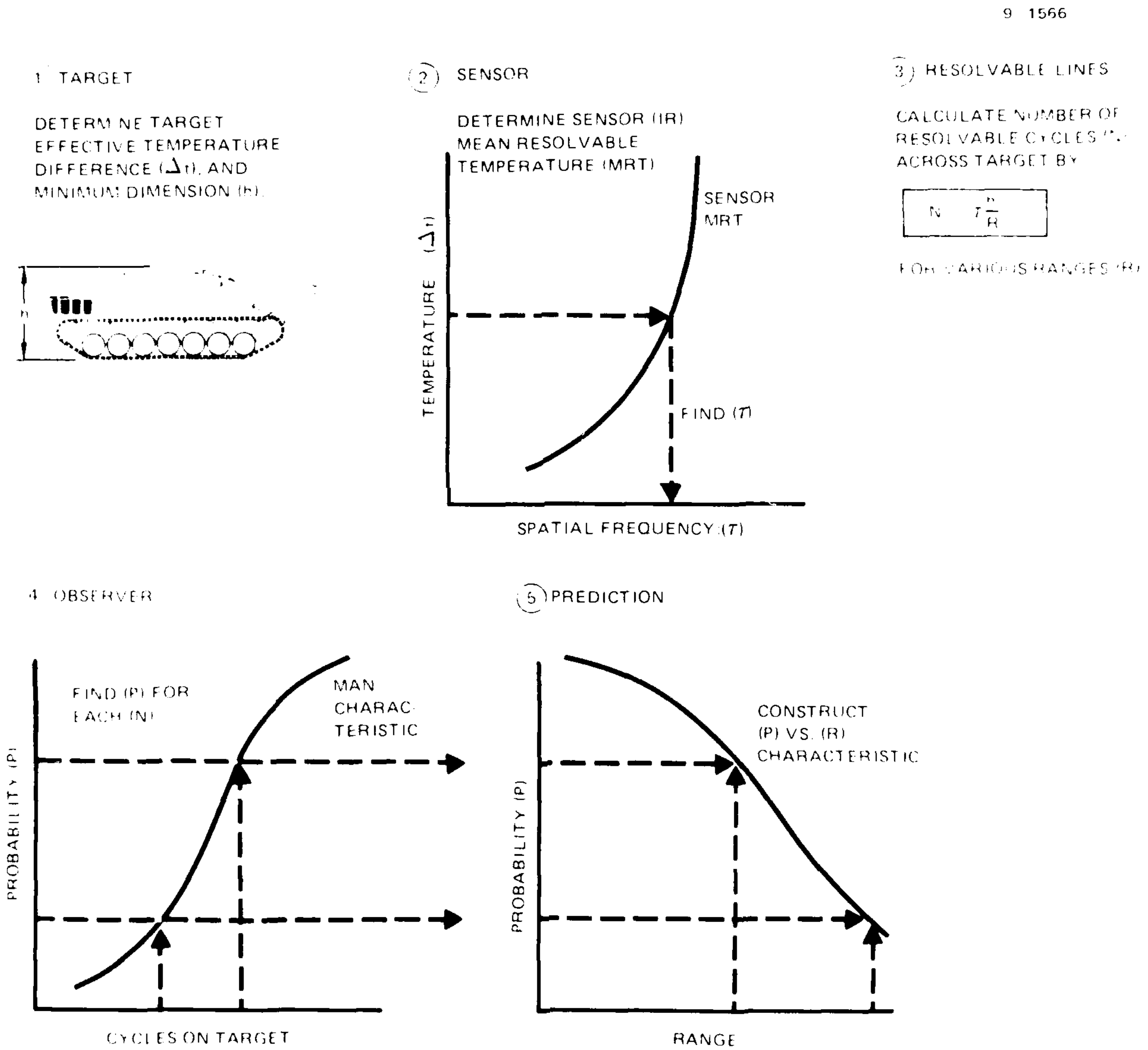



FIGURE 43 STEPS IN CALCULATING JOHNSON'S SIZE/QUALITY FORMULATION FOR AN IR SYSTEM (FROM JOHNSON AND LAWSON, 1974)

frequencies. Plotting both curves against spatial frequency yields a monotonically increasing function for CDF and a monotonically decreasing function for MTF. The area cutoff by these two curves is the MTFA (see Figure 44) and represents the spatial frequencies that the display can image and the eye can see over the range of modulation contrasts. The MTFA is a general measure of display quality; and, while it can be used to predict performance for a specific target, its major purpose is to determine which display will provide best acquisition for a variety of targets under a variety of conditions.

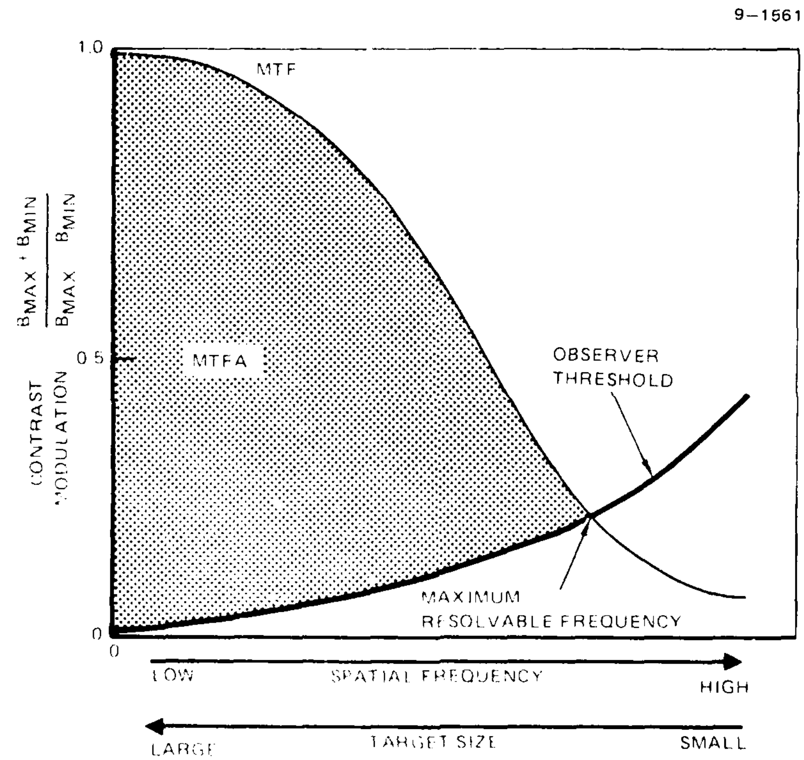



FIGURE 44 MTFA FORMULATION OF DISPLAY SIZE/QUALITY

All of the above measures make use of the concepts of display image quality and the observer's capability to make use of the displayed information, whether it is specific to a particular target size or generalized over a variety of target sizes and viewing conditions. To understand fully the assumptions being made by these approaches, it is necessary to consider resolution and contrast as they relate both to the target and the display image. Display resolution, or resolved spatial frequency, defines the amount of detail which can be seen on a display. As can be seen by the MTF, it is in part dependent on the contrast with which the detail is imaged and is not a truly independent parameter. For the purposes of this discussion, it is assumed that both contrast and resolution are adequate and in the area cut off by the MTFA. The most significant aspect of CRT display resolution is the breakup of the image in the vertical dimension by the scan line technique of image production. Theoretically, each scan line could represent one element of a standard bar pattern yielding an optical resolution equal to 1/2 the number of TV lines on the image. The actual resolution found on a raster type display is normally less than the theoretical limit, as scan lines are not imaged with a high degree of edge sharpness. A correction factor, called the Kell factor, can be obtained by dividing the raster pitch distance (scan line height) by the width of the picture resolution element (width of an element of the smallest resolvable bar target) (Fink, 1957). This can also be expressed as the ratio of the number of resolution line elements per millimeter to the number of TV lines per millimeter. This value has been experimentally observed to be about .7, although the actual value will depend on the specific display system. If the resolution on the display is greater than the observer's visual capability, the system is said to be observer-limited. A display-limited system provides less resolution than the observer can see. The ideal system would match the two capabilities. As indicated in the discussion of image quality models, some resolution is needed to define target detail in order for acquisition to occur. This detail must not only be resolvable on the display, it must be resolved by the observer, i.e., larger than one minute of arc.[7] This sets up a target size by resolution interaction. For a given target size, it appears that acquisition will improve up to some asymptote as resolution over target increases. The asymptotic performance level will depend on the type of target and the search requirements. For small, discrete, real world targets, the effects of size appear to level off at 20-30 minutes of arc (Elite Look, 1969; Erickson and Main, 1966). The resolution across targets appears to become asymptotic at from 15 to 20 scan lines across target (Self, 1971; Scott and Hollanda, 1970). A summary overview of scan lines across target requirements as a function of acquisition task and mission type is presented in Figure 45 (TAWG Working Paper, 1972). Probability of acquisition as a function of scan lines appears to be a two stage process, increasing rapidly in a linear fashion as scan lines increase and then, at some performance level, either leveling off or increasing more slowly until near 100% is reached (Self, 1971). This may be a reflection of perceptual process, on the one hand, and

[7] For high contrast details at a high brightness level.

decision process and observer differences on the other. Scott and Hollanda (1970) observed such a trend in their data which indicated 90 percent or better performance at 13.5 lines, but a reduction in spread of performance for both target types and observers at 20 lines-over-target. This latter effect may be due to range curtailment because near 100 percent performance was observed at 20 lines. Nonetheless, research into the parameters driving the break in the acquisition curve needs to be accomplished before a full understanding of the target acquisition process can be obtained.

9-1568

| CONDITION | REQUIRED NUMBER OF SCAN LINES | | |
|---|---|---|---|
| | DETECTION | RECOGNITION | IDENTIFICATION |
| 1 ACCURATE MISSION BRIEFING<br>TARGET LOCATION KNOWN<br>NO FRIENDLIES IN AREA<br>FEW CLUTTER OBJECTS<br>ACCURATE AIRCRAFT NAV SYSTEMS | 4 | 8 | 8 |
| 2 ACCURATE MISSION BRIEFING<br>TARGET LOCATION NOT PRECISELY KNOWN<br>CLUTTER OBJECTS PRESENT | 6 | 10 | 16 |
| 3 RECONNAISSANCE SURVEILLANCE<br>FRIENDLIES IN AREA<br>TARGET LOCATION NOT PRECISELY KNOWN<br>CLUTTER OBJECTS PRESENT | 6 | 15 | 20 |

FIGURE 45 ESTIMATED REQUIRED NUMBER LINES-OVER-TARGET AS A FUNCTION OF MISSION AND LEVEL OF DISCRIMINATION (FROM TAWG WORKING PAPER, 9 AUGUST 1972)

Stabilized image displays offer unique opportunities for investigating the effects of lines-over-target as the zoom associated with the aircraft closing on the target will produce a continuous variation in lines-over-target and target size. Since this process is continuous, each successive size is not independent of the previous one, however, valuable insights into the acquisition process may be obtained by careful recording of the size, target resolution and other target parameters at the time of acquisition. The Phase II study will be configured to [illegible] advantage of the target size phenomena inherent in the stabilized image dis-[illegible], and several classes of target size variables will be recorded and analyzed. [illegible] are detailed in Section 7.0.

Display Contrast - Display contrast is the relationship between the brightest and darkest areas of the image. Both the range between these two extreme values, called dynamic range and expressed in terms of gray shades, and the relationship between the scene luminance and the display luminance have been found to affect acquisition. Gray shades are derived from electronic measures of the signal and are usually defined as a three dB increase in signal strength. This is equivalent to a $\sqrt{2}$ ratio between the luminances of two adjacent levels. The light adapted eye has the capability of seeing a range of 14 gray shades, but full use of this capacity does not appear necessary for adequate target acquisition. Studies have shown (Slocum, Hoffman, and Heard, 1967; Johnson, 1968) that search of complex scenes requires at least seven gray shades, however for target identification of complex targets (no search was involved), performance with five shades of gray did not differ from performance with seven shades (Levine, Jauer, and Kozlowski, 1969).

Gamma, another characteristic of display contrast, is typically defined as the slope of the function relating log input luminance to log output luminance. It will determine whether the display luminance is greater (gamma > 1), equal to (gamma = 1), or less than (gamma < 1) the scene luminance. For FLIR systems, this relationship is between the effective scene temperature and the display luminance. Most studies of gamma have used photography rather than CRT displays. The results are mixed, some studies showing increased target detection (Blackwell, Ohmart, and Brainard, 1961) as gamma increased from 1.0 to 4.0, while others showed no effect for a range of gammas from .36 to 3.0. The effect of gamma on target/background contrast for a specific target depends on the initial contrast level. An increase in gamma for a target brighter than the background will increase the target/background contrast if the dynamic range of the system is not exceeded. For an IR sensor, certain portions of the target will tend to be the brightest returns on the image. Increasing this still further at the expense of the lower contrast returns will probably degrade rather than aid performance as low contrast detail will be lost. In general, from the relatively sparce evidence on the effects of gamma, a gamma near 1.0 appears to be the best compromise.

The hot portions of the target present another contrast problem with regard to measuring the brightness contrast between the target and the background. Contrast measures are usually taken as averages of both the target and background area in its immediate surround. This procedure greatly reduces the impact of the IR "hot spot," leading to artificially low predicted performance. An alternative procedure using a maximum target contrast measure, maximum target brightness vs average background (Krebs and Lorence, 1974), produced better performance prediction. Both measurement techniques will be used for the Phase II study.

5.3.2 Image Variables

These variables relate to the image characteristics which are independent of image quality. These include image scale, target aspect angle, scene complexity, target location, time-on-display, and a number of factors specific to a stabilized image sensor like rate of scale change and the overall effect of image zoom. Like the other variables discussed, these are highly interactive and, for the most part, can be traced back to the sensor/display system and antecedent/environmental variables.

Target aspect angle, scene complexity, and target location in the scene can all be related directly to the target and scene variables discussed in Section 5.1.1. Their appearance will be modified somewhat by the process of imaging by the FLIR sensor, but their effects on acquisition should not change.

Scale - Image scale is determined by the sensor field-of-view, range to target, and the display size. It will determine the target size on the display and the effects of aircraft motion on the image. The scale must be large enough to ensure adequate image target size for acquisition (see Section 5.3.1, Image Quality). Scale requirements, therefore, become a function of the real target size, since research has shown that the acquisition size for a given display appears to be a constant (Johnson, 1958; Erickson, 1976). Scale will also interact with aircraft speed to determine image motion and time-on-display. In general, the smaller the scale, the slower the rate of image motion, and the longer the time-on-display. The exact scale, image motion, time-on-display relationship, and the kind of image motion are dependent on the sensor geometry (see Section 3.2). Since scale also determines the ground area covered by the image, it will be a factor in determining whether the target is in the field-of-view and, to some extent, its location. In general, the selection of the best scale is a tradeoff between the required target size, time-on-display, and the probability of the target being in the FOV. Scale values for the Phase II study have been discussed in Section 4.

Time-to-Acquire - Time-on-display is a function of sensor geometry, as discussed above and in Section 3.2, FLIR System Geometry. Time is a function of image scale, display size, and aircraft speed for a moving window display and a function of FOV, image, display size, aircraft speed, and target location in the FOV for stabilized image displays. (Both cases assume simple geometry and optics.) The following data also assume adequate target size and resolution. It has been found that search time is exponentially distributed with the parameters of the exponential term dependent on the complexity of the target and the area to be searched (Krendel & Wodensky, 1960; Bloomfield, 1972). Simulations and field test studies of acquisition time have indicated that acquisition probability rises sharply for the first 10 to 20 seconds and then levels off to some asymptotic value as time increases beyond 50 seconds (Parkes, 1972; Bryson, 1972). Similar results were found for stabilized image displays when the targets were located in the central two-thirds of the display (Levine and Youngling, 1973) (see Figure 46). There is some indication that as time available is decreased, acquisition time per target also decreases. Thus, more targets will be reported per unit time in a time-limited search than would be reported in an unlimited time search. Comparisons of the results of time-limited and time-unlimited search made by Parkes (1972) indicate almost a 20 percent increase in targets reported for the limited search time conditions (see Figure 47). A stabilized image display, because of its configuration, will confound time-on-display with target size as the image zooms as a function of aircraft speed. Obtaining performance data with respect to this relationship is one of the major concerns of the Phase II study described in Section 7.0.

## 5.4 OBSERVER VARIABLES

Early studies of sensory processes found that measures of sensory thresholds usually varied from trial to trial. Subjects frequently reported that on some trials the stimuli were "easier" to detect than on others. Since many researchers made the implicit assumption that they were directly measuring the sensory capacity of the system under examination, the concept of a variable threshold was invoked to explain the results. However, due to more precise experimental design and measurement, data discrepant with the variable threshold concept have been discovered, especially with respect to the visual system. Cornsweet (1970) has pointed out that visual receptor mechanisms are highly stable. It is, therefore, doubtful that most experiments measured the sensory capacity for target detection, but rather measured the response criterion employed by the observer. Response criterion is a function of both the observer's sensory capacity, which is based on stable visual processes, and his response decision criterion which is affected by many physical, environmental, and psychological variables.

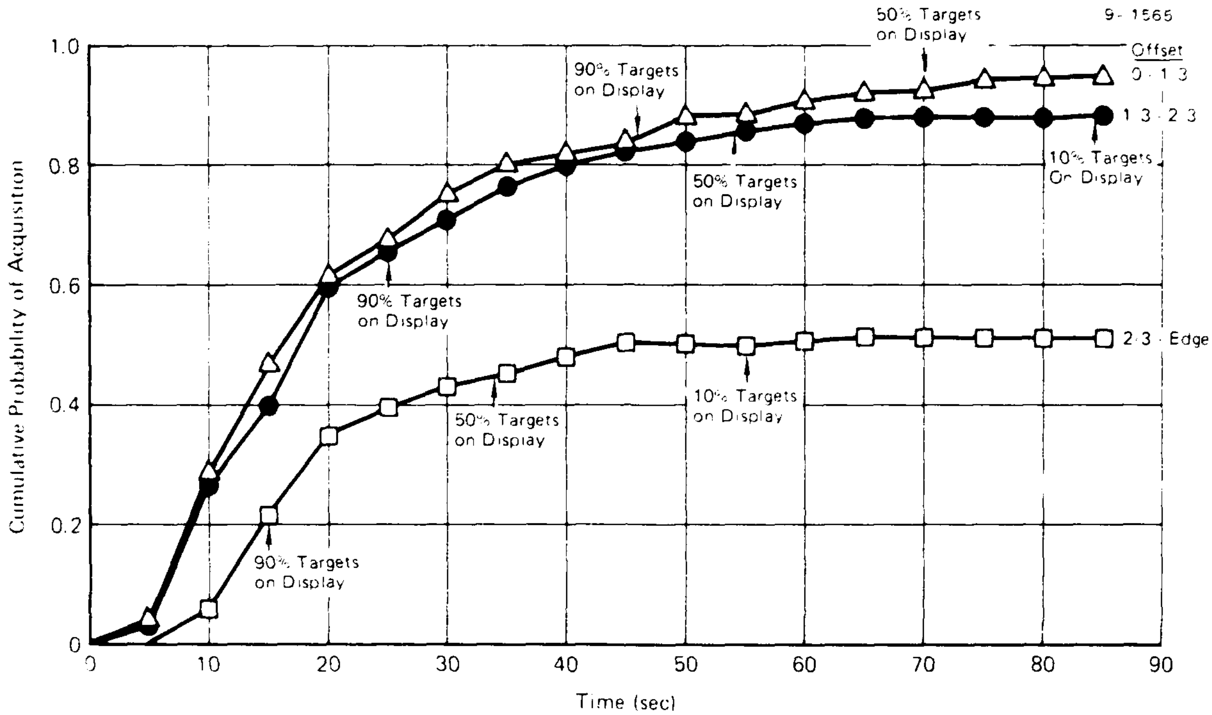



FIGURE 46 ACQUISITION AS A FUNCTION OF TIME ON DISPLAY AND TARGET LOCATION

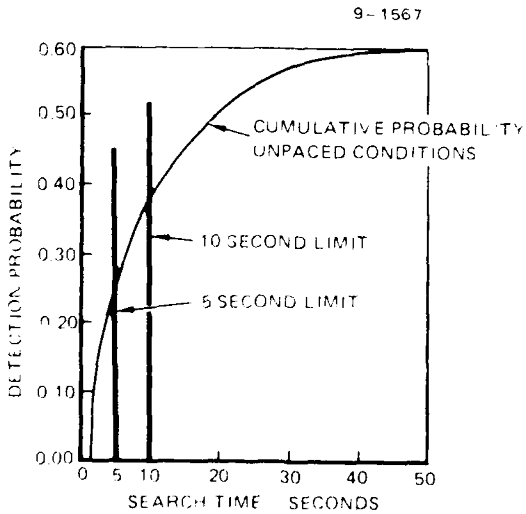



FIGURE 47 COMPARISON OF PERFORMANCE UNDER TIMED AND UNTIMED SEARCH CONDITIONS (FROM PARKES, 1972)

Signal detection theory, which was developed by communication engineers, has given rise to one of the primary techniques for discriminating between and measuring the observer's sensory and decision processes in target acquisition (Egan and Clark, 1966). In a signal detection experiment, the observer is presented either noise (N) or signal plus noise (SN) in a specified time interval. He is then required to indicate whether the SN was presented. The response will fall into one of four possible categories listed below:

| | | Event SN | Event N | |
|---|---|---|---|---|
| Response | Yes | 1 | 2 | 1+2 |
| | No | 3 | 4 | 3+4 |
| | | 1+3 | 2+4 | 1+2+3+4 |

| | Event | Probability of Occurrence |
|---|---|---|
| 1. | hit | 1/(1+2) |
| 2. | false alarm | 3/(3+4) |
| 3. | miss | 3/(1+3) |
| 4. | correct rejection | 4/(2+4) |

The observer's response is based upon the a priori probability of a SN trial and the probability that a stimulus resulted from an SN trial, relative to the probability that the same signal resulted from a N trial. Additionally, there is the willingness of the observer to make a response based on the consequence^ of the "yes" or "no" decision. The probability of a "yes" response on a SN trial may be calculated by the formula:

$$\underbrace{\frac{p(A/S)}{p(B/S)}}_{\text{aposteriori P}} = \underbrace{\frac{p(A)}{p(B)}}_{\text{apriori P}} \cdot \underbrace{\frac{p(S/A)}{p(S/B)}}_{\text{Likelihood ratio}}$$

where: p = Probability
S = Signal
A = Event one
B = Event two

and, A and B are mutually exclusive and jointly exhaustive events.

The observer usually employs a likelihood ratio to define his response, since he has the freedom to set the limits of this ratio.

There are a number of subject variables that affect the decision to respond "yes" or "no" to a given SN or N stimulus. First are the properties of the sensory analyzers which determine the absolute threshold of the observer. For the visual system, these include brightness sensitivity, adaptation level, and acuity. Physical/environmental variables that may affect both the sensory capacities and/or the response criterion include fatigue, workload, stress, ambient illumination, noise, and vibration. The response criterion is also affected by a number of psychological variables that center around the stimulus content, motivational variables related to the consequences of the decision, and the information and training available to the observer prior to the stimulus presentation.

### 5.4.1 The Visual System

The physiological limits of the visual system determine an observer's visual capabilities. These include threshold sensitivity for stimulation and SN discrimination functions of the visual system. The following section is concerned with the limitations that human vision places on target detection.

#### 5.4.1.1 Visual Acuity

Generally, visual acuity is defined as the ability of an observer to resolve differences in spatial patterns or the detail between light and dark areas. The size of the detail is usually expressed in minutes of visual angle. Visual angle $= 2 \arctan L/2D_d$, where L is the size of the object normal to the line-of-sight and $D_d$ is the distance from the eye to the object, usually called the viewing or eye relief distance. For angles less than one degree, which are typical of threshold measurements, the formula can be simplified to

$$\text{Visual Angle (in minutes)} = \frac{L}{0.0003D_d}$$

where $L/D_d$ represents the visual angle in radians, and 0.0003 is the number of radians per minute of arc. (This value is also equal to Arc tan of one minute of arc.)

Visual acuity data are usually given for some probability of detection. The threshold visual acuity is one which can be resolved 50 percent of the time. Normal visual acuity (20/20 vision) refers to being able to resolve a standard symbol at a standard distance 80 percent of the time. For display design, the probability requirements may go as high as 99 percent. This value is generally considered to be twice the 50 percent threshold value.

This method of expressing visual acuity is based on the definition of normal vision obtained from the ratio:

$$\frac{\text{standard distance at which a normal eye can discriminate 1 min of arc}}{\text{distance at which observer can descriminate 1 minute of arc}}$$

Using a standard distance of 20 feet, an observer having 20/10 vision could discriminate 0.5 minutes of arc; and one having 20/40 vision could discriminate two minutes of arc. Visual acuity is sometimes expressed as the reciprocal of the normal visual angle acuity of 1 minute of arc. Thus 20/10 vision would have a visual acuity value of 2, 20/20 vision a value of 1, and 20/40 vision a value of 0.5. This measure is a poor one in that the units of measurement do not correspond to equal increments of visual angle. It is included here only to acquaint the reader with its usage. All visual acuity statements made in this report will be limited to visual angle statements.

5.4.1.2 Detail Resolution

Three different types of detail resolution are generally used as measures of visual acuity: two point discrimination, vernier acuity, and minimum separable acuity. Two point discrimination is, perhaps, the simplest of the three and is defined as the minimum distance between two points at which the points are perceived as being separate. This measure of acuity finds its primary use in defining the limiting resolution of the eye for applications in astronomy and has no direct relevance to display technology. Vernier acuity refers to the smallest lateral displacement between two lines which can be detected. The amount of detectable displacement, as are all acuity measures, is dependent on the background brightness. The amount of displacement required for detection (called vernier acuity threshold) is very small, well below 10 sec of visual angle for most conditions. A general curve of the relationship between separation and background brightness can be seen in Figure 48 (curve A).

Minimum separable acuity refers to the smallest space the eye can detect between parts of a target. The targets normally used to measure minimum separable acuity are bar targets, checkerboard grids, and Landolt rings. Figure 48 (curve B) shows the relationship between brightness and minimum separable acuity for a high contrast resolution target.

The area of the retina stimulated will also affect visual acuity. The retina mosiac is made up of two types of receptors, rods and cones. Stimulation of the rod gives rise to perceptions of brightness while stimulation of the cones gives rise to perceptions of color. Due to anatomical connections in the retina and their overall physiological structure, the rods are more sensitive to light over all wavelengths than the cones and are responsible for scotopic or night vision (Figure 49). The cones can discriminate wavelength and can resolve stimuli to a greater degree than can the rods. They are concentrated in a central area of the retina called the fovea. Although it only subtends a visual angle of 2.5 degrees, this is the area of greatest visual acuity, making the eye a narrow FOV sensor with respect to resolving detail. Acuity and density of the receptors as a function of retinal location are shown in Figures 50 and 51, respectively. As seen in Figure 51, rods are most concentrated at about 20 degrees from the fovea. This area has the maximum acuity under low light level conditions.

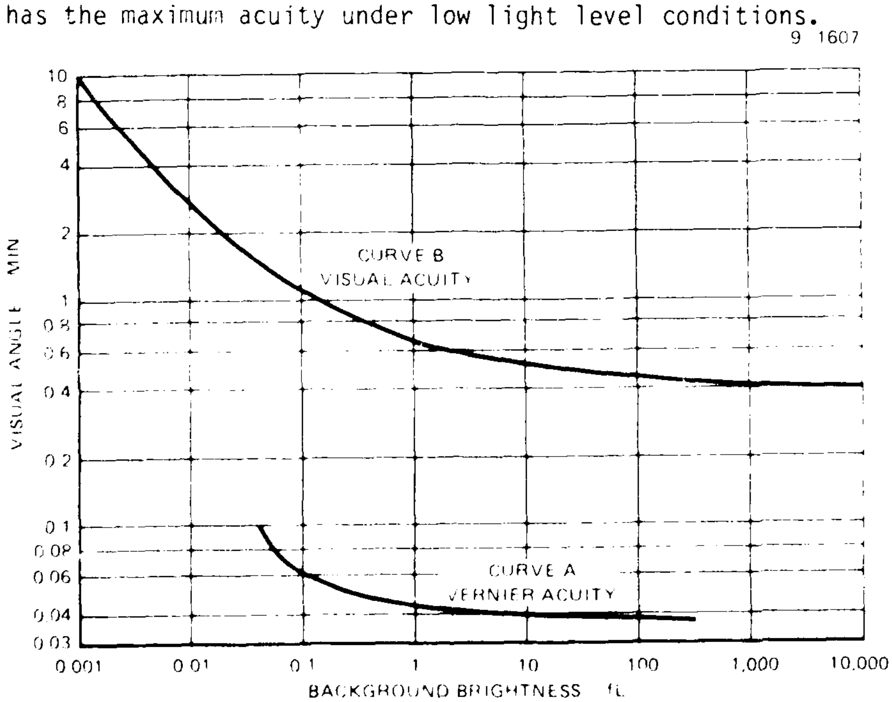



FIGURE 48 BRIGHTNESS AND ACUITY
(FROM WHITE, 1964)

5.4.1.3 Brightness Contrast Discrimination

The brightness contrast threshold refers to the ability of an observer to detect a luminance target 50 percent of the time. If the object is not imaged at a brightness level above threshold, it will be indistinguishable from its background.

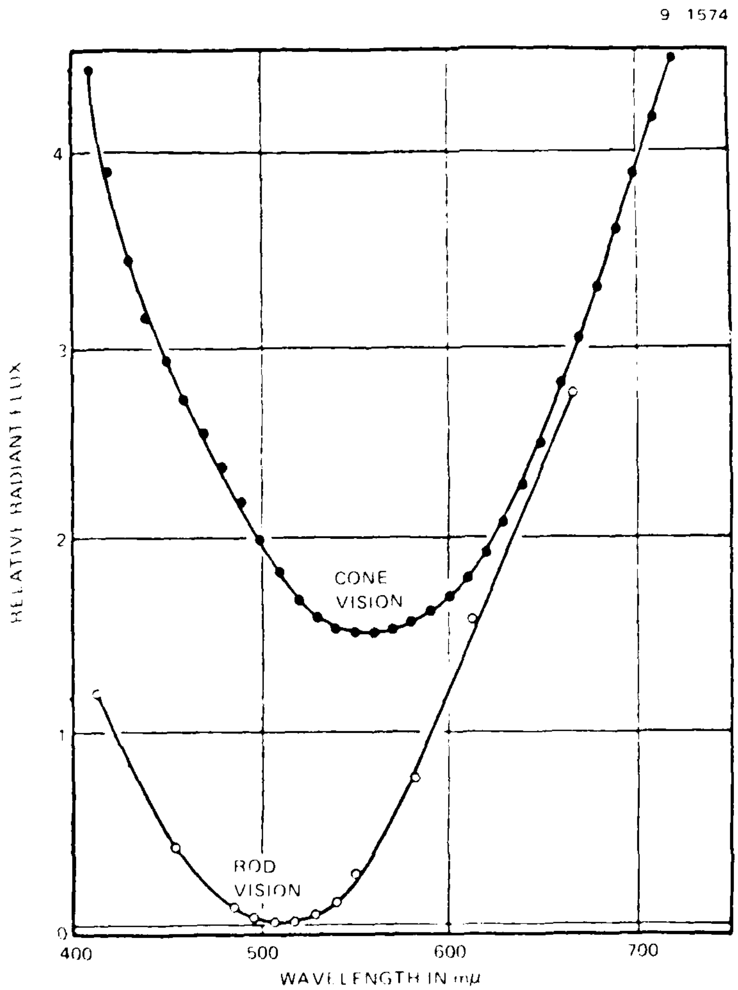



FIGURE 49 RELATIVE RADIANT FLUX REQUIRED TO STIMULATE RODS AND CONES (FROM CHAPANIS, 1949)

Blackwell and Taylor (1969) compiled data from an extensive series of studies in which circular stimuli projected on a uniform brightness background were presented to subjects. The results indicated that detectability generally increases as the size of the target increases up to approximately two percent of visual angle; and as presentation duration decreases, target contrast must be increased to maintain the same level of performance. Overall, they found that contrast discrimination varied as a function of target size, contrast level, duration of stimulus (for times up to 1/2 second), and the brightness sensitivity of the eye. Some general curves for visual angle and contrast detection are found in Figure 52. The values given refer to a 50 percent detection probability; however, other detection probabilities can be approximated from the baseline 50 percent data with the use of Figure 53.

The brightness contrast on a display is a function of both the display luminance and the ambient illumination reflected off the display face. The effect of the addition of ambient illumination on the contrast ratio is derived from the equation:

$$CR = \frac{(B_{max} + I) - (B_{min} + I)}{B_{min} + I} = \frac{B_{max} - B_{min},}{B_{min} + I}$$

where I = screen luminance addition due to ambient light.

This ambient light adds a constant to the display brightness values and reduces the proportional difference between $B_{max}$ and $B_{min}$. In aircraft cockpits, this ambient light can be as large as 10,000 foot candles causing severe degradation of display contrast, most notably a reduction in gray shades. Both high intensity CRT displays and special filtering have been used to alleviate this problem. Since solutions are available in the cockpit, the Phase II experiment will maintain at least seven gray shades dynamic range and a moderate illumination level, 100 foot candles throughout the study.

5.4.1.4 Adaptation Level

The visual receptors will vary in sensitivity as a function of the amount of light available and the time spent at that illumination level. This process,

9 1575

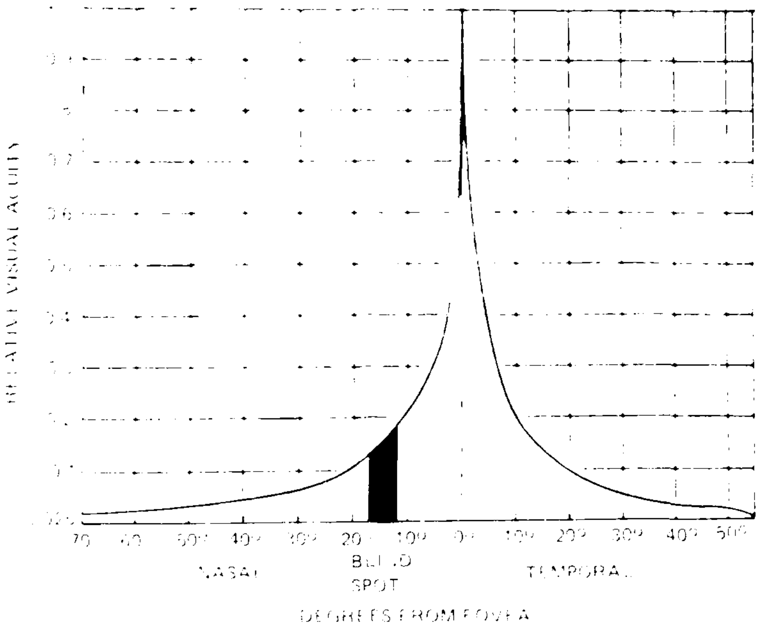



FIGURE 50 VISUAL ACUITY AT DIFFERENT RETINAL POSITIONS FOR PHOTOPIC VISION
(FROM CHAPANIS, 1949)

9 1576

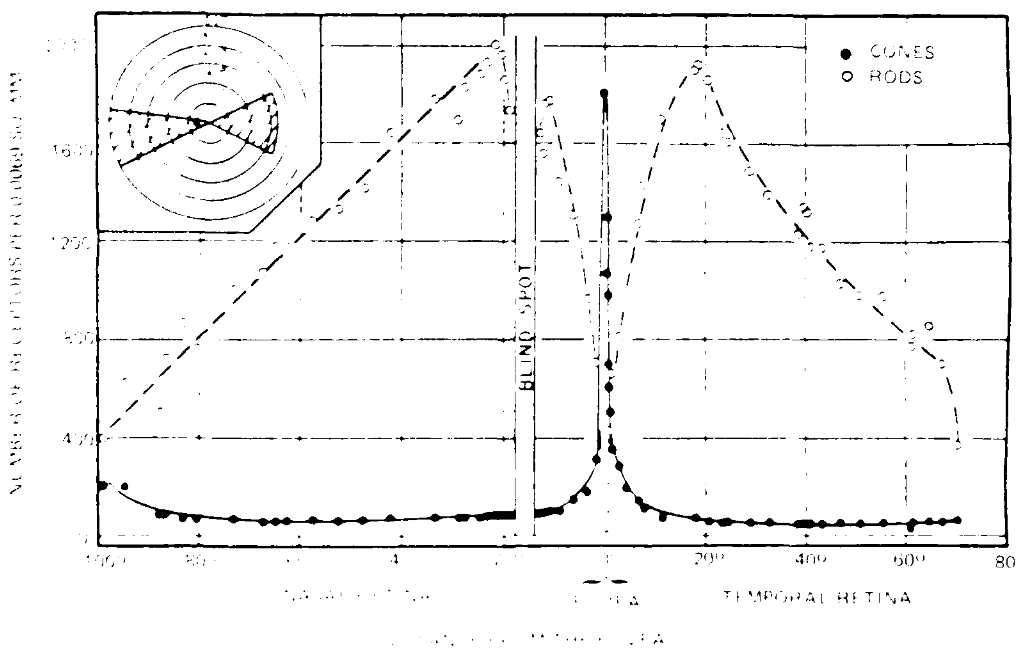



FIGURE 51 DENSITY OF CONES AND RODS IN HUMAN RETINA
(FROM CHAPANIS, 1949)

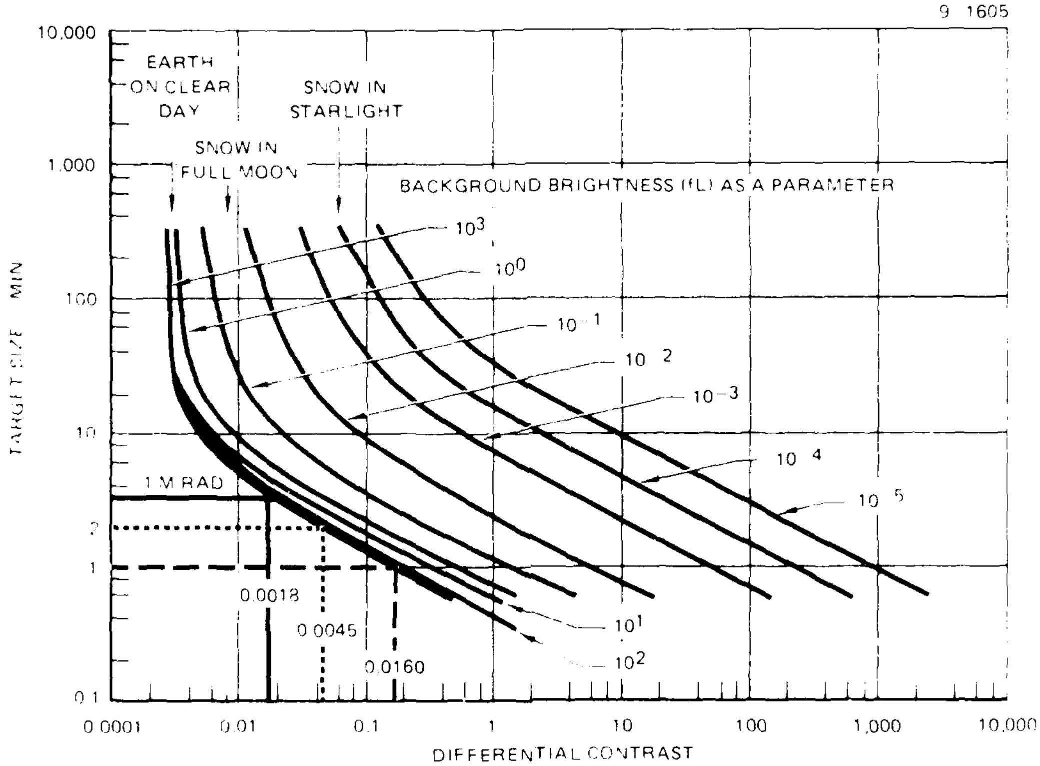



FIGURE 52 CONTRAST THRESHOLD AS A FUNCTION OF BACKGROUND (FROM BLACKWELL, 1946)

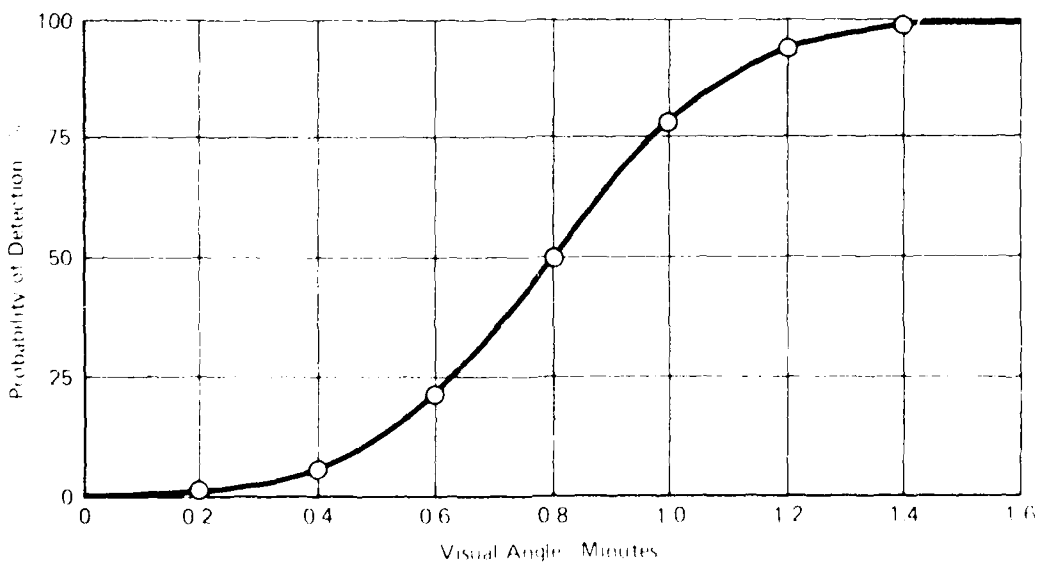



FIGURE 53 DETECTION PROBABILITY (FROM BLACKWELL, 1946)

called adaptation, compensates for varying light intensities to maintain good vision. The range of compensation can vary over as much as 10 log units, with adaptation to darkness taking considerably longer than adaptation to bright illumination levels. Dark adaptation as a function of time is shown in Figure 54. Dark adaptation occurs rapidly over the first few minutes; and by the end of five minutes, the threshold is approximately one mililambert, or about 1/100 of the brightness of snow in starlight. The fully dark-adapted eye is sensitive enough to detect a signal with an illumination level of approximately 90 quanta, a brightness level detectable only by sophisticated mechanical sensors. Because of these enormous shifts in sensitivity with changes in ambient illumination, the adaptation level of the eye must be considered in any displays where either the display or the environment can have large shifts in illumination. The critical factor here is to preserve, during exposure to higher illumination levels, the more sensitive dark adapted state of the eye.

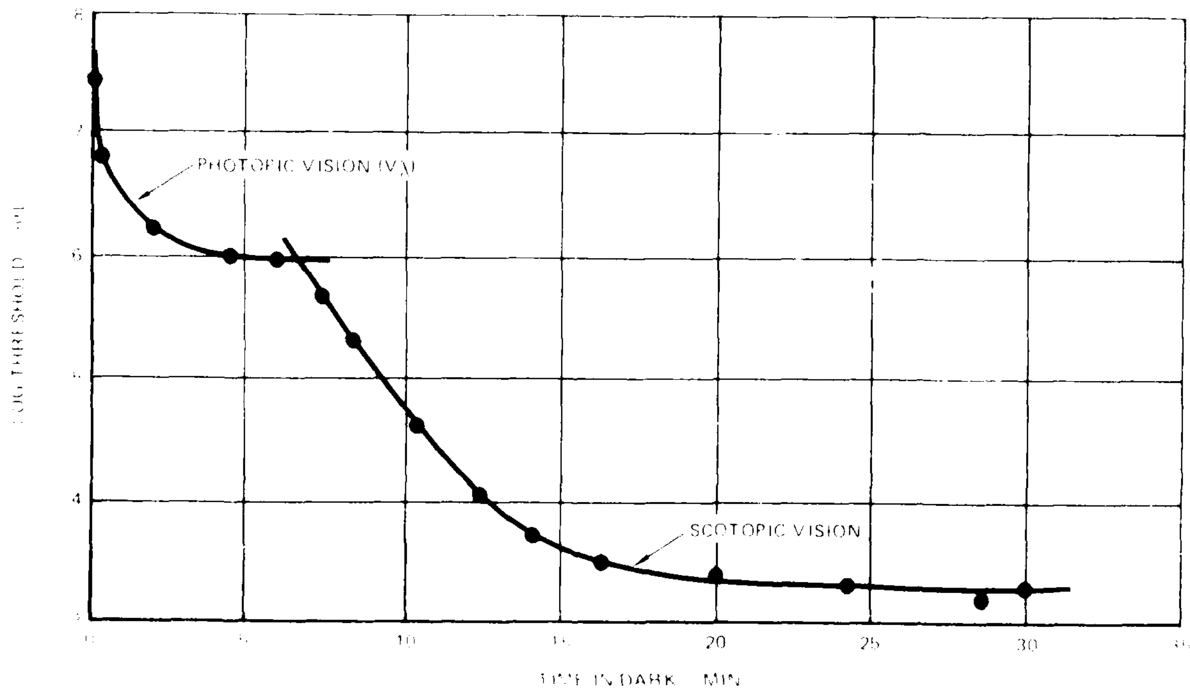



FIGURE 54 DARK ADAPTATION
(FROM JONES, ET AL., 1974)

Mismatch between the brightness of the display background and the surround can cause misadaptation, in that the eye will tend to adapt to the brightness of the surround. Where this difference is less than 10:1, the effect ...

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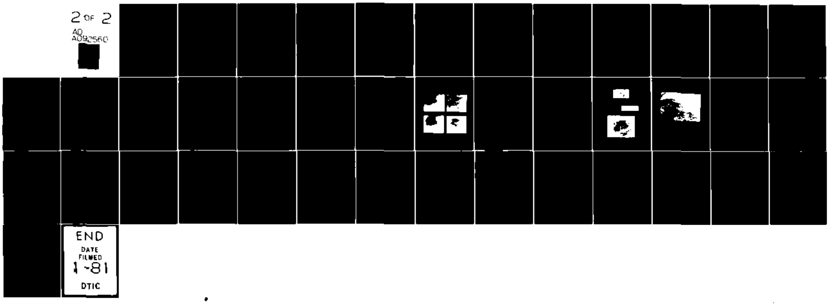
DYNAMIC FLIR TARGET ACQUISITION. PHASE I.(U)
AUG 78 S H LEVINE, L R BEIDEMAN F49620-77-C-0100
UNCLASSIFIED MDC-E1920 NL



however, larger ratios may require some modification of the brightness requirements for the display.

Considering the above factors, the Phase II experiment will employ a CRT screen display with the level of illumination set well above threshold stimulation levels and a constant room illumination to maintain the subject's visual adaptation level.

5.4.2 Physical/Environmental Variables

Many aspects of the physical task and the environmental workspace may be relevant to target acquisition; however, few of these have been adequately studied in a research setting. Generally, the effects of these variables have been categorized under the term stress, both physical and psychological. This section discusses selected stress factors and their effects on target acquisition performance.

5.4.2.1 Task Loading

Task loading, the performance of several tasks in a specified time period, is a typical procedure for pilots in an air-to-ground target acquisition task. Research indicates that target acquisition performance is not degraded significantly by light tasks performed during routine pilot operations; however, performance is degraded when complex flight operations are necessary.

Rusis and Calhoun (1965), using a compensatory tracking task, examined the effects of three levels of task loading on target acquisition performance as a function of range-to-target. Under heavy task loading, there was an increase in target recognition time and, as expected, a decrease in range for target recognition.

Price (1974) imposed a number and word reading subsidiary task on a primary target acquisition task using a television simulated scale terrain model scene with a changing line-of-sight. Target acquisition improved for this task. However, when the auxiliary information was presented on a separate monitor, there was a degradation in acquisition range-to-target. It is likely that in the first situation the additional task served to enhance attention while, in the second instance, the additional task required time sharing between the two tasks and divided attention.

5.4.2.2 Fatigue

The classic studies by Broadbent (1958) of fatigue effects during vigilence indicated that visual performance decreases over time unless operator arousal is maintained. Williams, Lubin, and Goodnow (1959) have found that operators have brief periods of "drop out" during vigilance tasks. They felt that these "drop outs" are in the form of one or two seconds of microsleep during which time the observer does not take in visual information or at least respond to visual stimuli. If targets are presented during this time period, they are missed. This decrement usually occurs after 15 minutes or more of search and may not be wholly relevant to the relatively brief period of target search found in air-to-ground acquisition. Stern and Bynum (1972), in a study of visual search using helicoper pilots, found that eye movements were reduced as a function of flying time. This indicates that fatigue may have significant effects on search efficiency beyond the simple vigilance decrement found by Broadbent. More research needs to be done in the area of fatigue and search for complex targets.

5.4.2.3 Noise

Noise stress has been examined in simple target detection tasks. Warner (1969), using 16 random letters, found no decrements in target search time under control, 80, 90, or 100 dBs white noise stimulation. In addition, error rate decreased as noise increased. In a second study, Warner and Heimstra (1972) presented either 8, 16 or 32 character groupings under varying levels of background noise. There was no difference in error rate as a function of background noise; however, search performance was superior at 90 and 100 dBs for the 32 letter display. As in task loading, increased arousal as a function of certain simple stimuli appeared to increase target acquisition performance.

5.4.2.4 Temperature

There has been little research on the effects of temperature stress on target acquisition performance. One study (Arees, 1963) tested 24 subjects in a simple monitoring target detection task at three levels of temperature: 55°, 75°, and 105°F. There were no significant differences in performance between the three temperature levels. One would expect, however, that at both high and low temperatures target detection would deteriorate, especially under high task loading and fatigue.

5.4.2.5 "G" Loading

"G" loading will have severe effects on the visual system. Research has shown (Cochran and Norsworthy, 1954) that at an average of four "G's" there is a loss of peripheral vision, and at 4.7 "G's," blackout typically occurs. Both absolute brightness threshold and contrast threshold are also affected by "G" forces. The absolute threshold was found to increase monotonically from 6.6 to 7.2 log units as "G" forces increased from one to four (White, 1960). Contrast thresholds approximately doubled as the "G" load went from one to five (Braunstein and White, 1962). Errors in dial readings, which have been shown to increase as a function of "G" load (Warwick and Lund, 1946), can be compensated for by increasing the luminance. This compensatory effect will occur at up to four "G" loads (White and Riley, 1958). Acuity was also found to deteriorate as a function of "G" load. Binocular acuity was found to vary linearly from .9 minutes of arc to 1.33 minutes of arc as "G" load varied from one to five (White and Jorve, 1956). Although no research dealing directly with target acquisition and "G" loading was found in this review, existing data tend to indicate that significant performance decrements can be expected above two "G" loads.

5.4.2.6 Vibration

Vibration has been shown to cause a loss in visual acuity and dial reading accuracy. The effects are related to the axis and frequency of vibration, the nature of the task, and whether the display and operator are both vibrating. These effects appear to be independent of relative amplitude, at least within the range of .025 to .05 inches (Mozelle and White, 1958). In general, the range of 10 to 25 Hz is most detrimental to visual acuity. Lower frequencies, below 10 Hz, tend to have stronger effects if the display or the display and observer are both vibrating (Hornick, 1973). Random vibration up to levels of .40 RMSG have not resulted in decrements in visual tasks, including target acquisition (Schohan, Rawson, and Soliday, 1965).

5.4.3 <u>Psychological/Experimental Variables</u>

While a large number of psychological variables has been suggested as having an effect on target acquisition, the practical number for this study is limited. The careful selection process implicit in screening pilots and test subjects, who are usually college students, yields a fairly homogeneous population of males with standard eyesight, above average intelligence, and generally good motivation. Studies on more subtle personality variables have yielded no significant measured differences that affect target acquisition (Seale, 1972). As indicated in the discussion of signal detection theory, the psychological variables will have their greatest impact on the decision criteria. Two variables which should have the largest effects on these criteria are motivation and training.

5.4.3.1 Motivation

It is generally assumed that personnel engaged in real world target acquisition are highly motivated. It may be due to this assumption that the effects of motivation on target acquisition have been rarely examined. Signal detection theory predicts that increases in motivation generally result in increases in both hits and false alarms. Bloomfield (1970) reported this type of result when using a money incentive to increase motivation in a visual search task. His study also indicated that false alarm rate did not increase as much as hits. More data are needed before any definitive statements can be made about motivation and target acquisition, especially the relationship between hits and false alarm rates.

5.4.3.2 Training

Training may be divided into three types: specific task, specific application, and general skills. Specific task training refers to training on a task highly similar to the actual task or the task itself. It includes what is usually referred to as practice. It can also include the first several trials of the task itself, provided that performance is improving over these trials. The assumption is made that if performance is improving, learning is taking place and therefore training is occurring. According to signal detection theory, the learning which is going on is not related to the task as much as it is related to a refinement of the decision criteria used in making signal present responses. In signal detection experiments, considerable practice is required before the response criterion stabilizes. These same phenomena may be occurring inadvertently in target acquisition tasks. To avoid the contamination of results by practice effects, the Phase II experiment will use an extended practice series of not less than 20 trials.

The other two types of training, specific applications and general skills, have produced significantly different results. General skills or experience appear to have little effect on target acquisition performance over a wide variety of test situations. Usually, comparisons are made between pilots, aerial observers or photo-interpreters, and students. The findings in almost all cases have been that the groups do not differ in performance (Erickson, 1966; Gilmore, 1965; King and Fowler, 1972; Rhodes, 1964; Krebs and Lorance, 1974). Some evidence has been found that the skilled groups have a smaller variance than the unskilled groups (Parkes and Rennocks, 1974; King and Fowler, 1972), but this can be attributed to the normal reduction of variance which occurs when a subject population is drawn from a restricted sample.

Specific applications training relates to search tactics, strategies, and skills which are specifically relevant to the display configuration and problem under consideration. Several studies have indicated that: the identification and training of required search skills yields performance equivalent to a full program of training at significant time savings (Thomas, 1964); detailed training in the special problems associated with specific sensors improved performance (Hagen, Larue and Ozkapton, 1966); and training based on the material to be encountered improved performance (Taylor, Eschenbrenner, and Valverde, 1970). Overall, these studies indicate that training which improves search techniques for the sensor in question or alerts the observer to specific target cues can improve performance. In the Phase II study, the observer will be presented with an unusual search format and novel target signatures. Training procedures will be instituted to ensure the observer is familiar with the stabilized image format and is aware of the search strategies best suited to this type of display. Additional training will be provided to familiarize the observers with the FLIR target signatures associated with each target at all levels of target infrared emissivity. Performance will be monitored during these trials to obtain insights into both training procedures and the learning process.

# 6.0 STUDY VARIABLES

Relevant parameters for ground stabilized imaging systems and the interaction among the parameters have been discussed in Section 5. In the present section, the particular variables selected for examination in the Phase II study are discussed, and an experimental approach which will provide meaningful operational data on target acquisition is developed. Specific ranges of values for the variables are identified based on the data reviewed in Section 5 and operational considerations and boundary conditions defined in Sections 2 through 4. The particular parameters were chosen to provide data for a core experiment. The results will be used as a data base to which experiments in Phase III may be related.

## 6.1 SELECTION OF PARAMETERS

The parameters selected for study in the core experiment include starting slant range, closing rate to target, target type and signature, terrain background, and speed. In addition, variables relating to time-on-display, display image quality, sensor FOVs, and downlook angles will be consistent with the effective aircraft envelopes defined in Phase I.

### 6.1.1 Target Type

The mission review in Section 2 identified vehicles in the 18-24 ft range as being typical targets for air-to-ground tactical strikes in the Eastern European theater. We have chosen three vehicles as being representative of the targets: a tank, a truck, and a half-track. While these targets are significantly different with respect to contour and internal detail, the similarities between the tank and half-track and the half-track and truck should provide a moderately difficult target identification task. Differences also exist with respect to the IR activity of the vehicles as the tank has a rear mounted engine, and the tank treads will have a different appearance to a thermal sensor than the truck tires. These differences should provide unique IR target signature cues to help differentiate between the vehicles.

### 6.1.2 Target Signatures

As stated in Section 5.1.1, IR target signatures are dependent on the heat distribution across the target or, more specifically, the $\Delta$Ts of areas on the target. These signatures can have significant differences from optical signatures depending on the target thermal history. To evaluate these effects, we plan to use two levels of thermal activity for each of the three targets. These levels are based on FLIR target acquisition operational demands and represent active and inactive targets. As identified in Section 2, vehicles frequently move at night and have the type of active "hot" thermal signature which IR technology was designed to detect. After the vehicle stops, there is a period of cool down in which the thermal signature gradually changes; but is still distinguishable from the background. This is the inactive target. Although a number of variables as discussed in Section 5 affect the signature, these variables will not be manipulated in the basic core experiment. Instead, the inactive and active targets will be used as two points on a continuum from which other target signature data may be derived. A third signature will also be evaluated, that of a TV sensor having the same general image characteristics as the FLIR system. This will serve as a baseline for comparison between the effects of the variables being studied on FLIR target acquisition and the bulk of the target acquisition literature relating to TV sensors.

An additional target condition will be included for the tank, that of an active tank with an active gun. Because of the unique characteristics of the gun/tank signature, this target represents the easiest possible vehicle target and should produce the longest acquisition ranges and the shortest response times. Operationally, however, it may be the most important target on a battlefield. Simulation of target signature activity will be achieved by first examining IR signatures and establishing a typical display to equivalent-temperature transfer characteristic. An appropriate pseudo-thermal encoded color scale will then be defined which, in conjunction with selected color separation filters, will provide the necessary video and displayed luminance levels. Details of this procedure are found in Section 8.

### 6.1.3 Target Background Complexity

Jones et al, (1970) have emphasized the interactive nature of the target-background effects on target acquisition. Many background factors, e.g., vegetation, clutter and terrain type, not only influence target detection and acquisition; but they also can modify the effects of other variables. These variables are usually studied under the general heading of target background complexity. A major difficulty in this area of research is defining and measuring background complexity. Zaitzeff (1971) refers to ambiguity, the number of possible target areas, and heterogeneity, the amount of internal differences in the background. Both are subjective metrics and measured by the judges' impressions. Rhodes (1964), in a study of target detection in air reconnaissance photographs, stated: "Raters were able to make highly reliable and seemingly valid judgments about complex perceptual characteristics of aerial photographs." Employing judged target difficulty criterion, 73 percent of the variance in target detection was accounted for. Therefore, in the present study, judged background complexity will be used to develop a scale of target background complexity.

A "mini-study" was executed to determine the feasibility of using observer judgments as a measure of target background complexity of a simulated terrain board. Seven observers were asked to judge the difficulty of finding tank targets in five different photographs of the terrain board and to rank order the photographs from the least to the most difficult. The photographs were selected based on the number of terrain features, the number of areas of target concealment, and clutter (vegetation and rocks). All observers ranked the photographs in the same order of difficulty for target detection (complexity).

Terrain areas of various target background complexities have been chosen for possible inclusion in the Phase II study. To develop a measure of target background complexity, photographs of these areas will be presented to 20 observers who will be asked to rate the photographs on a scale of one to seven. The mean rating for each scene will be calculated and used to identify the extreme rated scenes, simple and complex, and the median rated scenes. Three scenes at each difficulty level will be selected for inclusion in the study to represent the range of target background complexity.

6.1.4 Range-to-Target

For a given FOV, displayed target size is determined by overall display size, actual target size, and slant range to target. Changes in display size will produce changes in displayed target size, although the percent of the display subtended by the target will remain constant. Evidence exists (Bruns et al, 1970) that target acquisition performance is not affected by such changes. This hypothesis will be evaluated as part of the data analysis. For a given sensor system, actual target size and range to target will determine the size of the target in the FOV, the size of the target on a given display, and the proportion of the display it covers. Image dynamics in the system under study produce a steadily increasing displayed target size as range decreases. However, while a given target may be seen across a continuum of sizes over the course of the run, the length of time it is seen at these sizes will vary with the range at the start of the run and the rate at which range changes. We propose to use three operational starting ranges (20,000, 10,000, 5000 ft) to evaluate the effects of target size and available viewing time. A comparison of correct acquisition times will allow us to evaluate the perceptual effects of viewing the targets of smaller sizes over longer periods of time.

#### 6.1.5 Closure Rate

Closure rate is the speed in feet per second with which the sensor approaches the aim point of the system. In the case of an aircraft flying level with the sensor tracking the ground, the closing rate will be a function of vehicle speed and the line-of-sight from the sensor to the ground. As the vehicle approaches the target point, the closure rate will change as a function of the sensor/target geometry. In addition, the aspect angle of the scene will change as the sensor goes from an oblique to a straight down view of the target. At this point in the study, the inclusion of either of these effects would overcomplicate an already complex set of relationships. Therefore, Phase II will concentrate on a configuration where the aircraft is diving at the target area. The geometry of this flight path keeps aspect angle constant and reduces aircraft speed and closure rate to the same value.

The main perceptual effect of closure rate is the speed with which the scale of the scene imaged on the display will expand. This includes both the rate at which the target increases in size and the rate with which it migrates toward the edge of the display. At this point in our research, we are primarily interested in major effects, and no attempts will be made to differentiate the effects of rate of migration from rate of scale change.

Closure rate also interacts with target location to determine total time-on-display for targets offset from the sensor aimpoint. Time-to-impact or total possible time on display is equal to closure rate divided into distance to the center of the FOV (Range/Speed = Time). Time-on-display as a function of target location is a proportion of this total time equal to the ratio "D-d/D" where "D" is the distance from the center to the edge of the display along some radius, and "D-d" is the distance from the target to the edge of the display along the same radius (see Figure 55). Thus, time-on-display also changes as closure rate is manipulated to determine the effects of target rate of growth and migration toward the edge of the display. The same interaction exists between target location and time. The experimental designs and data analysis techniques appropriate for evaluating these interactive effects will be found in the experimental design section. Target offset will not be directly investigated as a variable; however, to control for target offset effects, the targets will be placed within the center 2/3 of the display. Placement in this area of the image has yielded consistent acquisition performance in previous studies (Levine and Youngling, 1973).

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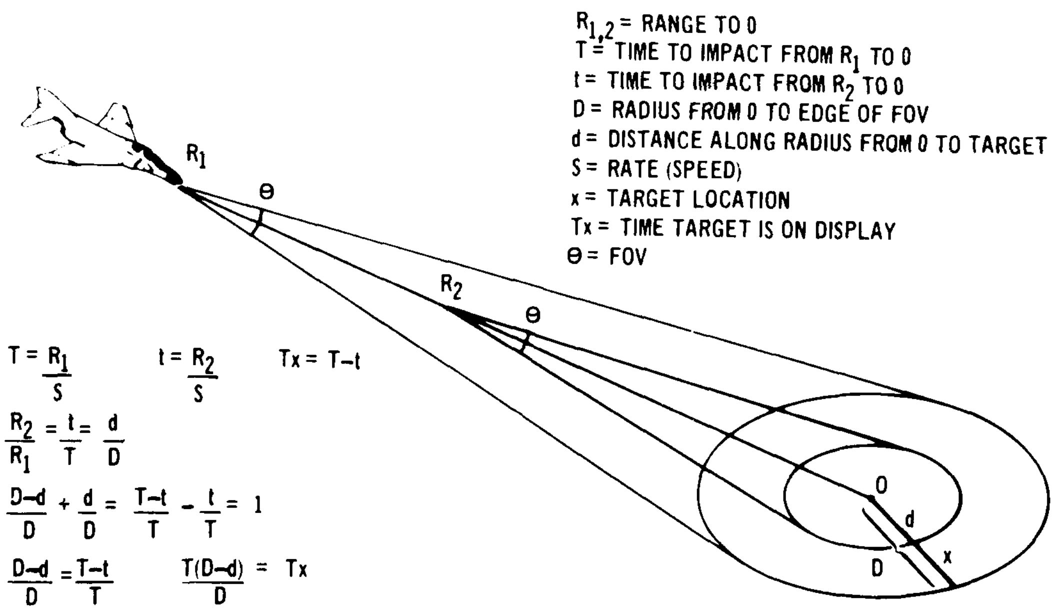


**FIGURE 55 CLOSURE RATE – TARGET LOCATION INTERACTION**

Closure rates of 250, 500 and 1000 feet per second (147, 294 and 588 knots at sea level) were chosen as providing a wide range of times on display for the various closure rate-range combinations. These times range from four seconds for the short range and high rate case to 64 seconds for the long range, low rate combination.

## 6.2 STUDY DESIGN APPROACH

Target acquisition is a complex task that is a function of many interactive variables. Since many target acquisition experiments have controlled a majority of the variables, thereby eliminating interactions, the results have not proved adequate for predicting target acquisition performance. One possible approach to the multivariate problem is to employ a response surface methodology. The approach was developed and used in situations that had a large number of suspected factors influencing a particular measurable event to determine which of these factors had significant impact on the event. Response surface methodologies attempt to account for event variability by establishing which of a large number of factors contribute to a multiple regression prediction equation establishing a functional relationship between those factors and performance scores. The variables sampled in response surface methodologies are assumed to be quantitative and continuous at the level of an equal interval scale.

Of the five variables selected for study in Phase II, only two, closure rate and starting range to target, meet this criteria. The target signature variables relating to target type and TV vs FLIR sensor images are nominal scale variables. The proposed subjective rating procedure places target background complexity somewhere between an ordinal and interval scale, depending on the rigor with which the scaling assumptions are applied. Because of this, we have chosen to use a core experiment approach rather than one of the response surface methodologies. This core experiment will provide a set of baseline data establishing the trends and effects of some of the more important variables. These and other measures outlined in Section 7 will be analyzed, using the same regression techniques which form the basis of the response surface methodologies, to develop an empirical prediction model. Future experiments will parametrically examine other variables affecting target acquisition in a manner which will permit an expansion of this empirical model.

# 7.0 STUDY DEFINITION

The previous sections have discussed the relevant parameters and identified their effects on target acquisition. This section integrates the variables selected for investigation with an experimental design and details the performan measures, statistical analysis, subjects, training, test procedures and controls to be used in the Phase II study.

## 7.1 STUDY DESIGN

The design is based on a block analysis of variance design including the parameters of range, speed, target type and signature, and background complexity (see Figure 56).

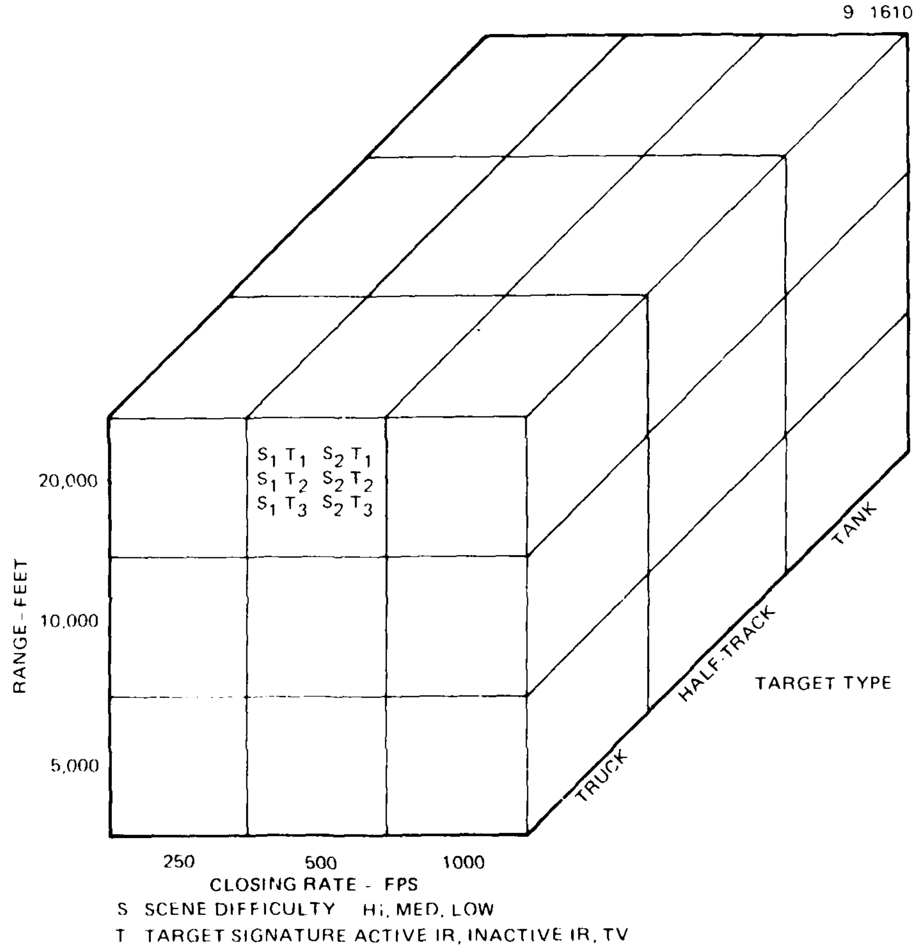


FIGURE 56 EXPERIMENTAL DESIGN

The three target types (tank, half-track, and truck), ranges (20,000, 10,000, 5,000 feet), closing rates (250, 500, 1,000 feet per second) and target signatures (active and inactive IR, and TV) will be integrated into a 3 X 3 X 3 design. An additional IR target, a tank having an active gun, will also be included in the study but analyzed outside of the central design. Three levels of target terrain background typical of the European theater having high, medium and low scene complexity will also be integrated into the design. Three scenes will be used at each level of complexity, and targets will be placed in the center 2/3 of the scene. The use of three scenes will avoid confounding level of complexity with a particular scene. Placing the target in the center 2/3 of the scene will require the subject to search for the target (it will not always be in the center of the FOV and therefore, predictable), allow sufficient time on display and control for the effects of target location in the FOV (see Section 6.1.5).

Each of eighteen subjects will be run under all conditions of the experiment with two exceptions: the three scenes at each level of terrain complexity will be varied systematically across subjects and the target signature and type at each location in the scene will be counterbalanced across subjects. Varying background scenes across subjects is a design economy measure that will allow fewer observations per subject. There will be 270 observations per subject, $3^5$ for the block design plus 27 observations for the active tank. The active tank signatures will be inserted randomly on the display throughout the experiment.

## 7.2 SUBJECTS

Where practical, subjects will be drawn from a subject pool of McDonnell Douglas personnel familiar with CRT displays and target acquisition. To ensure valid results, these subjects will receive special target acquisition training to bring them up to a criterion performance level before participating in this study. Candidate subjects will be screened before participation in the study to ensure adequate vision and instruction-following ability. Rigid vision requirements of 20/20 corrected vision will be set to reduce any variance attributable to acuity differences. By this same logic, subjects with better than normal vision will also be excluded from the study. Subjects will be screened for visual anomalies using a Titimus vision tester and a standard medical series of eye charts.

## 7.3 MISSION SIMULATION

A general purpose digital computer and associated I/O interface will be employed to conduct the experiment and to collect and store the data mechanically. The target scenes will be synthesized by a zoom optical imaging target generator which has four functions controllable by the computer system. These are the zoom focal length and its rate of change (corresponding to target range and closing velocity), and X and Y positions of the target scene (target location).

The target generator will use photographic transparencies as the primary imagery source and produce a collimated output beam containing the scene information. A standard 525-line vidicon TV camera will be fixed on the generator output beam and will reproduce the scene on the monitors.

The experiment controller's station will be comprised of a TV display and a CRT interactive computer terminal through which the simulation runs will be initialized. The controller will preview the scene and switch on the test display when the run is initiated. Subjects will view a 6-inch TV display from a fixed viewing distance of 28 inches. A low frequency, randomized angle dither will be added to improve the realism of the approach dynamics as an airborne sensor will not have perfect stabilization. When the observer can perform the designated target acquisition task, he will depress a switch which will cause an interrupt signal to be transmitted to the computer. The control program will then store the performance data in a disk file. Following storage, the computer will ask the experiment controller to initiate the next run from the terminal keyboard.

## 7.4 PROCEDURES

Training will begin with an explanation of the purpose of the study and a general description of the procedures. This will be followed by a review of FLIR signatures and a static target acquisition demonstration. Detailed instructions will be given concerning the definition of acquisition rules, relating them to the mission scenarios. Subjects will then be seated at the experimental station and asked to familiarize themselves with the operation of the target acquisition joystick. Acquisition will be achieved by slewing the cursor over the target and pressing the response button. This will center the target in the display. A second button press will simulate missile launch. Following this response, the observer will state the identity of the target. Several trial runs will be made using an adaptive training procedure, correcting false alarms and guiding responses to the correct target location and identity. After these familiarization trials, subjects will be given a series of 60 training criterion trials. We have set a skill level criterion of at least 80 percent correct responses in any sequence of 20 trials. Subjects not reaching this criterion by the end of 60 trials will be dropped from the study. The training trials will be selected from the midranges of all variables to yield a moderate difficulty level of acquisition.

We plan to use a two-hour test session on three separate days. Each will have ten sets of nine image runs separated by rest periods. The image generating equipment has a nine scene capacity accounting for 1/30 of the total images in the study. Calibration checks will be built into each run, and the experimenter will monitor all responses on a duplicate display. The details and target parameters of each run will be called up on the computer by the experimenter. Responses will be recorded automatically for later data reduction. Where possible, on-line data reduction techniques will be instituted as a means of monitoring the on-going data collection process. To maintain control over the training sequence, TV tapes will be utilized as a primary device. Strict experimental control of all the variables will be maintained, and frequent on-line calibration checks will be made. Cross-checks for computer input/output errors in variable selection will be instituted by a visual check of the input data against a displayed output at the start of each run. Additional procedures to protect the integrity of the experiment will be institutued as required.

### 7.5 PERFORMANCE MEASURES

Three subject responses will be recorded for target acquisition: 1) response to center target, 2) response to launch missile, and 3) target identification. These basic measures of target acquisition are concerned with whether a correct response is made. In order to obtain a clearer picture of performance, the occurrence of false responses will be recorded as a supplementary measure. From these two measures and their relation to the total number of possible correct responses, it is possible to generate a comprehensive description of observer performance. The proportion of correct responses to the total yields the probability of a correct response. The total number of correct responses divided by the number of correct responses plus false alarms yields a measure of target acquisition accuracy. The measures of where (range) or when (time to respond) the response occurs are also useful descriptions of performance that relate directly to operational concerns.

Because of the dynamic nature of the stimulus acquisition, performance can be defined as a function of stimulus state as well as the more typical performance measures. Therefore, we have idenfified the following additional dependent measures:

A. Target size
   1. Height
   2. Width
   3. Perimeter
   4. Cross section
   5. Area
B. Target Size/Display Size Ratio
C. Target Resolution

These measures will be related to target acquisition measures to provide greater predictive power for target acquisition and the design of such systems.

7.6 DATA ANALYSIS

The data generated in the study will be analyzed at a number of levels. The first will be a statistical analysis to identify those variables having significant effects on performance. These variables will be analyzed further to determine interactive effects and to generate general rules for system design, and, where possible, they will be related to basic perceptual processes. The structure of the experiment lends itself to the collection of data for the evaluation of a number of hypotheses of search and acquisition, target size-display size proportion constancies, and minimum target size-resolution relationships. Specific tests of the applicability of these hypotheses will be made from the performance data acquired in the experiment. Additional restructuring of the data will be made to generate engineering and design guidelines for system design by expressing the performance data as a function of aircraft and sensor system parameters.

## 7.7 STATISTICAL ANALYSIS

Separate data analyses will be performed for measures of target acquisition, target size at acquisition, acquisition time, and range-to-target. Accuracy, completeness, and false alarms will also be considered. Statistical analysis techniques will include, but not be limited to, analysis of variance and multiple regression. Multivariable analysis of variance will be used where appropriate. Relationships among the variables will be presented graphically for both simple effects and interactions. Where practical, investigation will be made to determine if any variables combine to generate complex predictive measures. For example, other studies (Levine, Jauer, and Kozlowski, 1973) have found that the signal-to-noise ratio can be combined with target size and display resolution to yield a unitary metric, resolvable-lines-over-target. This metric predicted performance better than any of the parameters taken separately. Probability contour curves will also be generated for several criteria levels, e.g., 90, 80, 70 percent correct acquisition. These curves represent the values and combinations of variables which will yield a particular performance level. Where appropriate, analysis will be performed using the Biomedical Computer Programs which are available in the McDonnell Douglas Automation Company. Care will be taken to ensure compatibility of both the experimental design and the formatting of the output data of the collection computer with these analytic programs. This procedure should produce significant savings in analysis time.

# 8.0 SIMULATION APPROACH

A part-task simulation of the critical display features found with a high performance imaging FLIR system will be used to generate the stimuli for this study. This approach has three major simulation tasks: the IR signatures, the mission imagery, and the target/scene dynamics. Considerable in-house research has already been done in this area, and facilities exist for the accurate and efficient execution of each of these tasks. Details of this simulation approach are presented in the following sections.

## 8.1 TARGET SIGNATURE SIMULATION

Target signature simulation will be achieved by first examining IR signatures and establishing a typical display-to-equivalent temperature transfer characteristic. An appropriate pseudo-thermal encoded color scale will then be defined which, in conjunction with selected color separation filters, will provide the necessary video and displayed luminance levels.

### 8.1.1 Target Signature Dynamic Range

The displayed gray scale is determined by the target's radiant emittance, which is transformed into spatial and intensity modulation of target equivalent thermal "gray scale" and then modified by the overall sensor/display system input-output transfer characteristic or "gamma." It is not sufficient to establish the displayed dynamic luminance range only in terms of displayed black and peak white levels; intermediate levels must also be displayed at adequate contrast ratios. Sample signatures have indicated that a linear relationship exists between target ETs and the Electronic Industries Association (EIA) logarithmic gray scale, the eight middle steps of which are believed adequate to display most expected ETs.

The task of the simulation is to accommodate those conditions, which typically exist in instances of gun firing or extreme engine heating, and to preserve an accurate and realistic displayed target IR signature. It has been shown that signal compression or truncation through peak white clipping of this type of high level signal is considered acceptable or even desirable in preserving target signature spatial characteristics and internal contrast.

The eight middle steps of the EIA $\sqrt{2}$ step scale[8] represent brightness levels extending from about 60 percent reflectance white to 4.4 percent reflectance black, for a dynamic range of approximately 14:1. It must be remembered, however, that this contrast range has many more visually discriminable shades of gray than the eight standard $\sqrt{2}$ brightness ratio steps used to define the scale. Volkoff, in a study of brightness discrimination on CRT displays (Volkoff, 1971), found a 1.074 brightness ratio between steps would yield accurate gray level discrimination. The 14:1 range found in an eight level 8 $\sqrt{2}$ gray shade display will allow 36 discriminable gray steps in the display. Distributing this range over the extreme E$\Delta$T of 80°C yields a temperature discrimination of 2.2 degrees. Using the same values and clipping the extreme intensities to preserve detail in the lower temperature areas of the scene will produce an E$\Delta$T of approximately 40°C and a temperature discrimination of a little over one degree. Feasibility studies have been successful in generating 10 $\sqrt{2}$ step gray scales which will potentially increase the capability of the system.

### 8.1.2 Simulation Technique

The use of pseudo-color is often employed in IR photography and thermography to enhance identification of hot or cold areas. In the Dual Mode Colorimetry system developed in MCAIR's Flight Simulation Laboratory, false color is used on appropriate scene elements in conjunction with color separation filters to model the scene thermal characteristics for real-time television display. The TV camera views the full color scene plus pseudo-thermal encoded color targets through color separation filters, one for the electro-optical (EO) and another for the IR. The filter-color coding combinations yield equivalent EO or IR sensor returns preserving or reversing contrast relations of bright/cold and dark/hot objects as appropriate to the conditions being simulated. Figure 57 illustrates the use of the pseudo-thermal encoded painted models on a full color scene to depict hot and cold targets.

The televised scene retains the desired visual gray scale derived from natural tones of desaturated green, yellow, and orange in the EO mode while providing a significantly altered "thermal" gray scale for the IR mode. As shown in the figure, neutral terrain gray scales are well preserved in both modes. The

[8] The $\sqrt{2}$ is used to approximate the 2.45 ratio used in the EIA scale.

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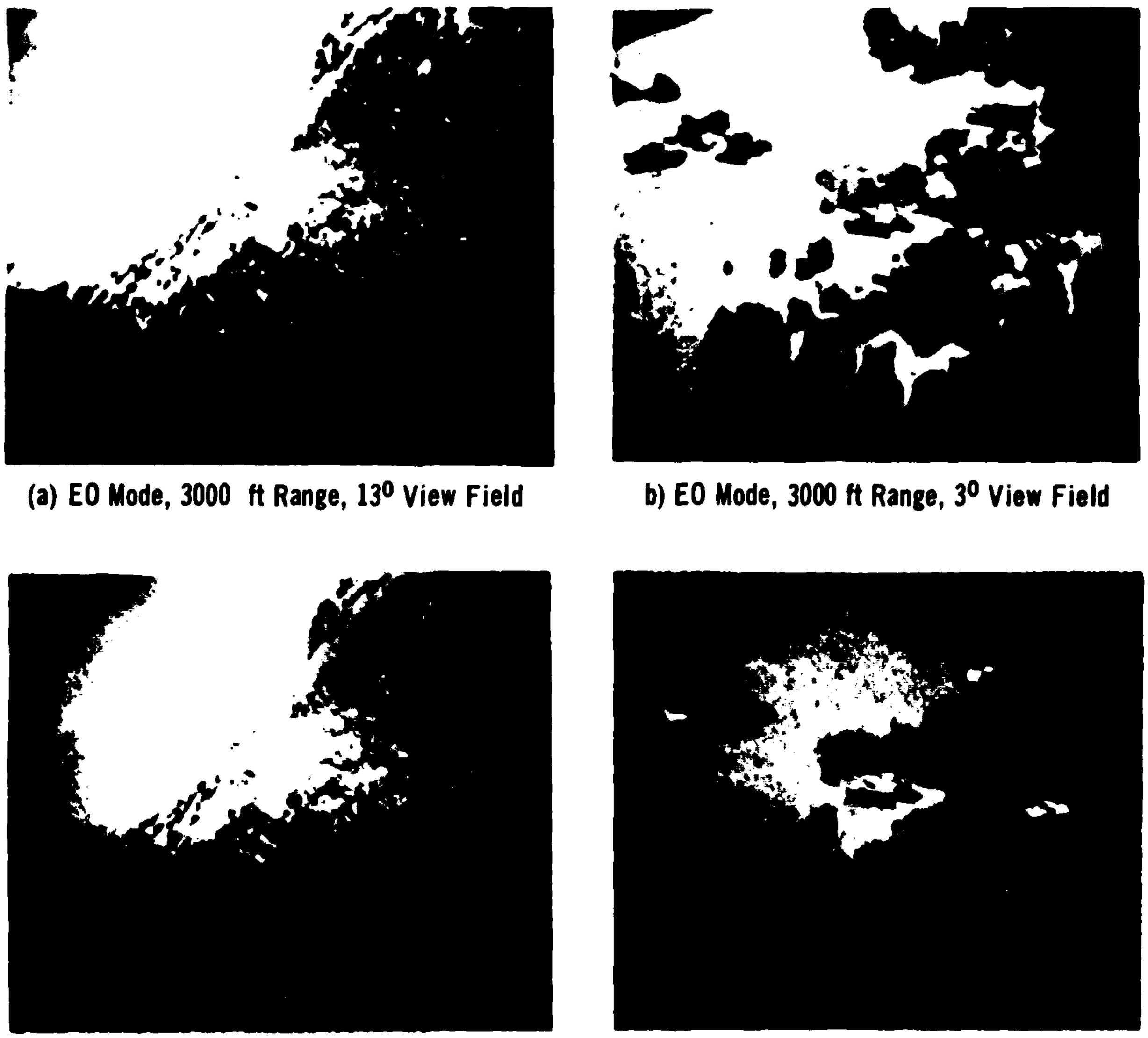

(a) EO Mode, 3000 ft Range, 13° View Field

b) EO Mode, 3000 ft Range, 3° View Field

c) IR Mode, 3000 ft Range, 13° View Field

d) IR Mode, 3000 ft Range, 3° View Field

FIGURE 57 EO/IR TELEVISION DISPLAY SIMULATION

Dual Mode Colorimetry approach described here is required in the EO/IR simulation to provide the necessary mode-to-mode gray scale dynamic range. In the film-based single mode system to be used in this study, this requirement has been relaxed, although the use of pseudo-thermal encoded color and bandpass optical filtering is advantageous in providing an expanded gray scale for target signatures.

Simulation of a single IR mode sensor display is unencumbered by the dual mode reversal requirements and TV camera response trade-off considerations present in the EO/IR system. In the film-based single mode system, a broader dynamic range is available through the use of a filter having greater peak transmissions tailored to the pseudo-thermal color encoding of the target without sacrificing color separation capability. The use of color and filtering has demonstrated a dynamic range increase of almost 2:1 over that achieved using a black/white gray scale having the same unfiltered photometric dynamic range (Figure 58).

9-1609

| STEP NO | COLOR | NO FILTER | COLOR SEPARATION FILTER | ASA 32 PAN X FILM | PAN X FILM WITH COLOR SEPARATION FILTER | SIMULATED CORRELATED TEMPERATURE, °C (TARGET) |
|---|---|---|---|---|---|---|
| 1 | ORANGE | 85 | 1 13 | .71 | 1.13 | 112 |
| 2 | RED ORANGE | 59 | 81 | 67 | .97 | 98 |
| 3 | RED | 43 | 56 | 64 | .60 | 68 |
| 4 | DEEP RED | 30 | 40 | 63 | .22 | 34 |
| 5 | MAROON | 26 | 31 | 59 | .10 | 23 |
| 6 | VIOLET | 19 | 23 | 54 | .06 | 15 |
| 7 | BLUE VIOLET | 15 | 13 | .37 | 04 | 13 |
| 8 | DARK BLUE | 11 | 08 | 14 | .03 | 12 |

*NORMALIZED TO 98% REFLECTANCE WHITE BaS04 CHIP ILLUMINATED AT ABOUT 4000°K.

**FIGURE 58 WIDE RANGE COLOR SCALE REFLECTANCE CHARACTERISTICS**

An experimental single mode 8 \ 2 density step color scale has been developed and applied to IR modeling of a typical target. Figure 59 illustrates the color scale, typical target model, and television display. Additional thermal modeling efforts required to reproduce the target signatures selected for the study are currently being conducted.

Selection of the color scale and color separation filters will be based on spot photometer measures of a closed circuit TV image of the color scale filmed on pan X stimulus slides. The encoded colors will be developed to provide the desired television gray scale as measured with the photometer. The incremental, simulated ET levels and correlated display gray scale will be established from the filtered color to display transfer characteristics. Color mix formulas will be recorded, and the color samples will be documented by recording their absolute spectral characteristics over the visible region. These encoded paints will then be applied to the target models according to the thermal intensity distribution established by the signature characteristics chosen for the study.

### 8.1.3 Stimulation of Mission Imagery

The scale of the terrain and target can be set at any value as long as enough detail is present at maximum magnification to maintain the realism of the simulation and enough detail is present at minimum magnification to simulate realistic fields-of-view, altitudes, and depression angles. Detailed scale models of armor and wheeled vehicles are currently available at scales of 1:285. Using this scale as a baseline, a ten foot square area on our terrain map will simulate approximately one-half mile square coverage. The detail in the terrain map is sufficient at this scale to simulate bushes and low scrub trees (vegetation heights of 15-20 feet). This detail maintains good realism at high magnification as can be seen from Figure 60. These values are presented to indicate the feasibility of obtaining properly scaled target background photographs from the terrain board.

## 8.2 TARGET ACQUISITION SIMULATION

As indicated in Section 7.0, an overall hybrid target acquisition simulation will be synchronized by integrating infrared signatures of tactical targets with the production of authentic mission imagery and attack dynamics. This type of simulation can be accomplished through the use of either a relief terrain map with a three dimensional base or a zoom optical imagery target generator. Each of these approaches has its advantages, and the utility of each depends on the particular objectives of the simulation. The terrain board simulation provides realistic dynamics and geometrical aspect of model targets. Many different mission trajectories can be simulated. On the other hand, the zoom target generator provides an inexpensive and versatile method of simulating target closure at a

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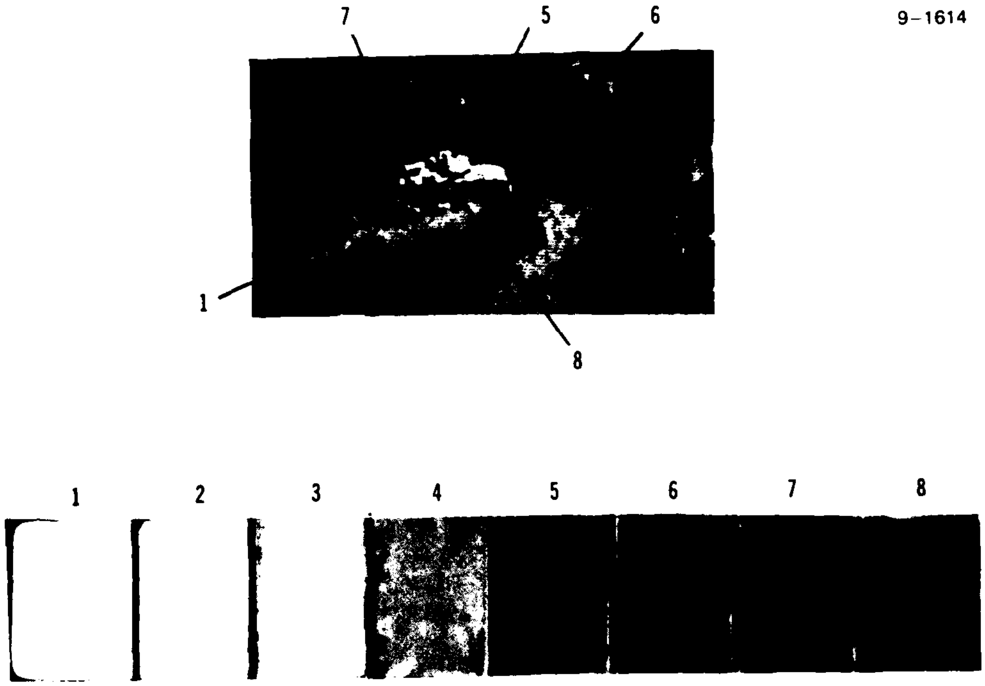


(a) 8 Step Color Scale and Model

(b) TV Display with Wratten 24 Ref Filter

FIGURE 59 SINGLE MODE WIDE RANGE IR SIMULATION fixed aspect angle. This approach allows easy control of aimpoint, approach velocity, and angular dither of the sensor.

9-1615

FIGURE 60 SCENE FROM TERRAIN BOARD SIMULATION

For the Phase II study, an approach utilizing a terrain board and a zoom imager will be used. As described in Section 8.1, the terrain board will be used to generate photographic imagery for this phase of the study. The optical filtering technique, with target model paint encoding, can produce well controlled target signatures simulating FLIR response. These photographs will be used in the zoom imaging target generator for the experimental runs. The zoom system has several functions which are computer controlled. This provides flexibility and facility in sequentially presenting different run conditions. For example, values of closing velocity and angular dither rate are designated by the experiment controller at the start of each run.

8.3 VALIDITY DEMONSTRATION

In order to evaluate the realism of the simulated FLIR imagery, a comparison between selected operational and simulated imagery will be presented on our simulation equipment. Measurements of the target signatures on the operational imagery will be used to duplicate the targets in our simulation facility. Comparisons between display quality and target acquisition data for the real and simulated imagery will be made. If significant differences are found, our simulation technique will be modified, and the comparisons will be repeated. We will continue this iterative process until correspondence in performance and display quality measures between the real and simulated imagery is achieved.

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# 10.0 GLOSSARY

| | | |
|---|---|---|
| AAA | - | Antiaircraft artillery |
| A-10 | - | USAF close air support aircraft |
| APC | - | Armored personnel carrier |
| BLIP | - | Background limited infrared photoconductor |
| $B_{max}$ | - | Maximum brightness |
| $B_{min}$ | - | Minimum brightness |
| CDF | - | Contrast demand function |
| CF&S | - | Counter force and strategic |
| CRT | - | Cathode ray tube (display) |
| dB | - | Decibel |
| DIA | - | Diameter |
| DME | - | Distance measuring equipment-A technique for internally guiding weapons as a function of the distance traveled by the weapon |
| E T | - | Equivalent temperature difference |
| EIA | - | Electronic Industries Association |
| EO | - | Electro-optic |
| EW/GCI | - | Electronic Warfare/Ground Control Intercept |
| FEBA | - | Forward edge of battle area |
| FLIR | - | Forward looking infrared |
| FOV | - | Field-of-view |
| FPA | - | Focal plane array |
| "G" Load | - | Gravity load - relates to forces exerted on the body due to positive or negative acceleration |
| GBU-15 | - | USAF modular guided glide weapon system; details classified |
| Hz | - | Cycles per second |
| ICBM | - | Intercontinental Ballistic Missile |
| IR | - | Infrared |
| KTS | - | Knots |
| LLTV | - | Low light level television |
| LOAL | - | Lock-on after launch - Weapon delivery technique requiring target lock-on after the missile has been launched. This system requires the use of a sensor in the weapon and a data link back to a controller. |

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|---|---|---|
| LOBL | - | Lock-on before launch - This weapon guidance system requires that the controller lock the weapon on the target before launch. This system requires that the weapon contain some sort of tracking device. |
| LOC | - | Line-of-communication |
| M | | meter |
| $\mu$M | - | micrometer |
| MACH (number) | - | Speed of sound - will vary with altitude |
| MAVERICK | - | USAF/Hughes Aircraft Co. AGM-65 A/B air-to-surface missile |
| MCAUTO | - | McDonnell Douglas Automation Company |
| MDAC-St. Louis | - | McDonnell Douglas Astronautics Company - St. Louis |
| MDC | - | McDonnell Douglas Corporation |
| MRT | - | Mean resolvable temperature |
| MSSDEF | - | Missile and Space System Development and Evaluation Facility |
| MTF | - | Modulation Transfer Function |
| N | - | Noise |
| NATO | - | North Atlantic Treaty Organization |
| NVL | - | Night Vision Laboratory |
| PARALLEL SCAN IR | - | Infrared detectors are arranged in an array aligned perpendicular to the direction of scan, and the output of each detector forms the video signal making up the composite scene. |
| PAVE TACK | - | USAF night attack weapons system; details classified |
| POL | - | Petroleum-Oil-Lubricant |
| RMSG | - | Root mean square "G" |
| S | - | Signal |
| SAM | - | Surface-to-Air Missile |
| SA-1 (GUILD) | - | The SA-1 was first shown in Moscow in 1960. About 12m long and .70 cm in diameter, this missile is classified as part of the Soviet strategic air defense force. The estimated range of this missile is 32 km. While still in service, it is slowly being replaced because of obsolescence. |

SA-2 (GUIDELINE) - This medium range air defense missile has been exported in large numbers to many countries outside the Warsaw Pact. These include Cuba, Egypt, Indonesia, Iraq, North Vietnam and Yugoslavia. This missile became operational in 1958 and is slowly being replaced by more modern systems. It is technologically obsolete and not very effective against modern ECM measures. The SA-2 is launched from a fixed site having a highly typical pattern of five to six missiles grouped around a central radar scanner. The missile is 10.7m in length and 50 cm in diameter with a 130 kg warhead. Improved versions vary somewhat from the original. It is estmated that the missile has a 40-50 km range with a 18,000m ceiling.

SA-3 (GOA) - The GOA is a two stage missile designed for air defense against low flying aircraft. Introduced in 1961, this missile is widely distributed among the Warsaw Pact nations and their allies. The missile is said to have 15 km range and a 12,000m ceiling. The same missile is also shipborne for sea-to-air defense.

SA-4 (GANEF) - The SA-4 is a land vehicle missile mounted two to a vehicle, and first seen in Moscow in 1964. The missiles are mounted on armored tracked vehicles which suggest an air defense role in forward areas. The missile is also believed to have a ground-to-ground capability. The missile is 8.8m long, 90 cm in diameter, and has a medium to long range capability covering a range of 70 km and an altitude of 15,000m.

SA-5 (GAMMON) - This is a large strategic air defense missile with both anti-aircraft and antimissile capability. It is located primarily in the interior of the Soviet Union. First deployed in 1963, this missile has a range 250 km and a ceiling of 29,000m. It is about the size of a Nike-Zeus having a length of 16.5m and a diameter of 80 cm.

SA-6 (GAINFUL) - First shown in Moscow in 1967, this rocket-boosted, ramjet medium range missile is capable of cruise speeds of up to 2.5 Mach. This high speed drastically reduces the time for evasive maneuvers in comparison to the older SA-2 and SA-3 missiles. The missiles are mounted in threes on a PT-76 light tank chassis, and the Straight Flush radar fire control system is mounted separately on a similar vehicle. The SA-6 has a range of 30 km for low altitudes and up to 60 km at high altitudes with a 4 km minimum range limit. Its maximal altitude is from 15,000 to 18,000m with a low altitude intercept limit to 100m. The highly explosive 80 kg warhead probability contains 40 kg of explosives and can be proximity fused as well as detonating on impact or on command. The missile is approximately 62m in length and 33.5 cm in diameter.

SA-7 (GRAIL) - The SA-7 is a man-portable, shoulder fired, antiaircraft missile. The operator otically acquires the aircraft and fires the IR homing missile to achieve a tail pursuit kill. This missile may have been deployed as early as 1967 and has been used successfully in North Vietnam to shoot down helicopter. The SA-7 is effective against aircraft flying above 500 feet and below 450 to 500 knots. It has an operational range of 3.2 km and a ceiling of 2500m. The missile has a 1.8 kg warhead and measures about 1.3m in length and 10 cm in diameter. During the Yom Kippur War, SA-7s were seen mounted on tracked battlefield vehicles, but these may have been the missiles designated as the SA-9 (an improved SA-7).

SA-8 (GECKO) - This short range, low-level, air defense system was first se in Moscow in 1975 and is designed to fill the air defense ga between the ZSU-23-4 and the SA-6, SA-7 and SA-9 missiles. is believed to be a derivative of the shipborne SA-4 missile This self-contained system, radar and four missiles, is mounted on an armored, three-axle vehicle. The missiles are approximately 3.2m long and 21 cm in diameter. It appears that the launchers can be rotated through 120 degrees rearwa to allow an automatic reloading sequence initiated from insi the vehicle. The missile carries a 40-50 kg warhead and has 10 to 15 km maximum range with an assumed speed in the regio of Mach 2. The configuration of the radar would allow simultaneous engagement of two independnet targets by the two tw launchers. It is assumed that two missile salvos would be launched at the target, one missile shortly followed by the other. A backup optical target tracker is also included in the system.

SA-9 (GASKIN) - The SA-9 is thought to be an improved version of the man-portable SA-7 carried on two twin launchers mounted on a modified wheeled BRDM-2 armored personnel carrier. This sho range missile is said to have a more powerful propulsion system, larger warhead, and better maneuverability than the SA-7. This system or a precursor was used in the Sinai and Syria during the Yom Kippur War.

SN - Signal pulse noise

S/N - Signal-to-Noise Ratio - a measure of signal strength

SNRD - Signal-to-Noise Ratio at the Display - A measure of display/image quality used in Russell's model

S-60 - This towed 57 mm antiaircraft gun is in general use throughout the Warsaw Pact nations. The gun is radar controlled and has both aerial and ground fire capability. The maximum rate of fire is about 120 rounds per minute with a practical rate of 70 rounds fed in clips of four rounds each.

TRAM - USAF night attack system; details classified

TV - Television

ZSU-57-2 - This is a self-propelled 57 mm antiaircraft system mounting two S-60 guns on a tracked carrier. This system is optically guided and has a maximum range of approximately 500m vertically and 12,000m horizontally. Both 57 mm systems have a maximum antiaircraft range of 8000m.

ZSU-23-2 - The ZSU-23-2 is a 23 mm fully automatic, air-cooled, twin barreled antiaircraft cannon. This towed version is optically guided. It has replaced most of the 14 mm AAA in the Warsaw Pact nations. Using a box-type, 50 round magazine, this gun has a 1000 round per barrel cycle rate, although the actual rate of fire is approximately 200 rounds per barrel. The gun has a maximum antiaircraft range of 5000m and an effective range of 2500m.

ZSU-23-4 - This is a self-propelled version of the ZSU-23-2. It carries four water-cooled 23 mm guns mounted on a tank chassis. The ZSU-23-4 is radar controlled and has proved to be a highly effective, low-level antiaircraft defense system. It has been in operation since 1965 and provides an organiz air defense for both motor rifle regiments (four per unit) and tank regiments (eight per unit). A total of 2000 rounds, 500 per gun, is typically carried by the vehicle. The gun ranges are the same as the ZSU-23-2.

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